Appendix 3

Hydrologic and Water Resources

Hydrologic and Water Resources Technical Appendices to the Carlsbad Project Water Operations and Water Supply Conservation Environmental Impact Statement

INTRODUCTION

This technical appendix to the Carlsbad Project Water Operations and Water Supply Conservation Environmental Impact Statement contains 8 individual contributions. These documents contain technical details regarding individual components of the Pecos River Decision Support System (PRDSS) and associated modeling and processing of data used for alternatives impact analysis.

As described in Chapter 4 of the EIS, the PRDSS is comprised of several linked modeling tools that are used to quantify Pecos Basin hydrologic responses to management actions. While Chapter 4 presents the overall PRDSS impact analysis results with respect to the water resource / hydrologic resource indicators, technical details related to the analysis (including descriptions of modeling tools, approaches, and assumptions) are provided technical documents listed below. Included in the list with each document title is a brief description of how that particular document relates to the analyses in this EIS.

- Results Memorandum for Alternative Modeling Using Bypass Water: This document describes surface water modeling of alternatives, including bypasses and block release restrictions, without Carlsbad Project Water Acquisition (CPWA) or additional water acquisition (AWA). It provides flow duration results and net depletions results along with background information and interpretations of the modeled output.
- Pecos River Bypass and Additional Water Needed (AWN) Modeling and Post-Processing: This document details RiverWare modeling and post-processing calculations for bypass operations alone, and computation of additional water needed (beyond the bypasses) to meet flow targets for the PBNS 100% of the time. Summary results are presented.
- Pecos River RiverWare Model Offset Modeling Documentation Report: This report describes the surface water modeling of CPWA options with the Taiban and Acme Constant alternatives. The report presents modeled results and interpretations for effective CPWA reaching CID, and also presents derivations for Brantley transit efficiencies, along with estimated Brantley transit efficiencies.
- Pecos River RiverWare Model Additional Water Acquisition Modeling Documentation Report: This report describes the surface water modeling of AWA options. Improvements (and degeneration) of intermittency and flow duration from AWA options are presented as results along with some interpretation.
- New Mexico-Texas Stateline Modeling and Post-Processing Report: This memorandum addresses the assumptions and methods used to compute impacts of operational alternatives and selected Water Offset options modeling on flows at the New Mexico-Texas Stateline. It also provides summary results.
- Roswell Artesian Basin Ground Water Model Technical Report: This report summarizes the application of the RABGW model to the EIS alternatives analysis. The document focuses in particular on RABGW analyses of the Carlsbad Project Water Acquisition options of groundwater rights retirement and installation of an augmentation well field to supplement the chronically short Carlsbad Project water supplies
- Analysis of Intermittency: This memorandum describes the calculation of intermittency in the upper critical habitat reach (focused specifically on the near Acme gage). In particular the conditional probability and confidence interval

methods and results are developed and presented. Length of intermittency is also investigated, and the results emphasize comparison by hydrologic season.

- Geomorphology Technical Memorandum: This memorandum documents a field reconnaissance visit from Sumner Reservoir to Brantley Reservoir along the Pecos River. It illustrates the different geomorphic conditions found along the Pecos River in this reach. It also provides channel geometry predictions for the modeled flow duration of alternatives.

Each separate document is intended to disclose to the interested members of the public details related to distinct aspects and/or water resource indicators that were not included in the main body of the EIS. Besides this technical appendix, additional supporting documentation related to the hydrological and water resource investigations undertaken in support of the EIS can be found in the EIS Administrative Record.

In particular, essentially all of the hydrologic analysis and evaluations presented here and in the body of the EIS were provided through the collaborative efforts of the Pecos River Hydrology Working Group (HWG), which has maintained an Administrative Record (AR) of all of their activities. The HWG is a multiagency / Pecos Basin stakeholder group that has been meeting on an approximately monthly basis since 2000. Jointly led by representatives of the US Bureau of Reclamation and the New Mexico Interstate Stream Commission, the HWG included representatives from Carlsbad Irrigation District, Fort Sumner Irrigation District, the US Army Corps of Engineers, Debaca County, and Sandia National Laboratories, and on occasion other stakeholders. All of the modeling tools and methodologies described in Chapter 4 and the following technical documents were developed through the HWG. Important investigations, analyses, and issues scoping undertaken by the HWG are documented in detailed notes taken at each meeting, and in memos, reports, and PowerPoint presentations prepared by HWG members. Some of these reports provide yet more detailed coverage of the modeling tools than that found in some of the following technical appendices. All of these items can be found in the HWG files as part of the EIS AR.

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Results Memorandum for Alternative Modeling Using Bypass Water

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Preface

The following memorandum was first drafted in the fall of 2004 by Alaina Briggs with the contributions of other NEPA Hydrology / Water Operations (HWG) members. This preface was attached to the current version of this memorandum to explain the changes made to the memorandum for inclusion in the HWG's Technical Appendix in support of the Carlsbad Water Operations EIS. The alternative reoperations modeling (with the absence of water acquisitions) is a piece of a larger picture of NEPA hydrologic analyses and modeling that included such aspects as: alternative reoperations, Carlsbad Project water acquisition (CPWA), State-line flow, additional water acquisition (AWA), geomorphology, and sub-sets of the aforementioned aspects of analysis and modeling including Roswell basin modeling (which applies to CPWA), and finally Carlsbad basin modeling (which applies to State-line flow modeling).

Included in the original memorandum were intermittency, flow exceedance, and net depletion analyses. The intermittency and flow exceedance information was for the most part left untouched in this revision; however, the net depletion section was extensively rewritten to account for new perspectives on interpreting the modeled output. Now included in this document is a detailed breakdown of net depletion sources to CID from reoperations using 60-year modeled averages. These concepts were originally presented in a draft of the "Pecos River RiverWare Model CPWA Modeling Documentation Report" (Stockton Engineering and Tetra Tech, 2005a), but were removed and inserted in this document since they directly applied to the results presented in this document. Also included are estimated maximum annual transmission losses in the reach from Sumner Reservoir to Brantley Reservoir due to bypass operations only. In addition, a section is now included showing the effects of comparisons using net depletions that can indicate erroneous net depletions. Net depletions to State-line flows were also reworked to remove the effects that temporally unequal modeled spills can have on indicating erroneous maximum and minimum net depletions to State-line flows. All of these improvements and the revised supporting methods for interpreting output were included in the revision of the memorandum. The methods in this memorandum are current with the results presented in the Public Draft EIS for Carlsbad Project Reoperations.

1.0 Introduction

This memorandum summarizes hydrologic impacts (based on model results) of NEPA alternatives to reoperate Sumner Dam for the Pecos bluntnose shiner (PBNS) and discloses modeling limitations and assumptions associated with the quantification of those impacts. The analysis and results discussed in this memorandum were completed as part of the Carlsbad Project Water Operations and Water Supply Conservation EIS.

The results used to evaluate the hydrologic impacts were determined by the Hydrology/Water Operations Work Group (HWG) using a surface water model (Tetra Tech, 2000b, 2003b, 2003d), two groundwater models (Hydrosphere, 2003c; Barroll, et al., 2004), and an output post-processor (Hydrosphere, 2001a). The aggregate of these models is referred to as the Pecos River Decision Support System or PRDSS. Impacts examined by the HWG include:

1) Anticipated changes to flow frequency at select river locations corresponding to USGS gage locations;
2) Amounts of total water needed to meet demands for each flow target alternative for instream flows to benefit the PBNS, referred to as "total water needed";
3) Amounts of water available from Carlsbad Irrigation District / Carlsbad Supply (CID supply) to meet demand for instream flows to benefit the PBNS, referred to as "water bypassed";
4) The net of the two aforementioned amounts, referred to as "additional water needed", for times for when CID supply is not great enough to meet the demand;
5) The reduction in total irrigation supply to the CID due to bypassing flows and modifying block releases through Sumner Dam for the PBNS, referred to as "net depletions to CID";
6) The net impact to water deliveries at the state line, referred to as "net depletions to State-line flows".

2.0 Alternatives and the Pre-1991 Baseline – Parameter Summary and Assumptions

The alternatives and baseline examined by the hydrology work group are shown in Table 1. The No Action Alternative represents operations on the Pecos River according to the current (2003-2006) Biological Opinion (BO) of the U.S. Fish and Wildlife Service (2003). The pre-1991 baseline represents operations on the Pecos River before 1991 when the system was operated solely for efficiency.

In addition to the No Action Alternative and pre-1991baseline, five other alternatives were examined. These alternatives vary mostly by target flow stipulations. Two of the alternatives specify target flows at the Taiban gage (Taiban Constant and Taiban Variable); two alternatives specify flows at the Acme gage (Acme Constant and Acme Variable). The Critical Habitat Alternative specifies: flows at the Taiban gage (in the non-irrigation season), flows at the Acme gage during normal and wet hydrologic periods during the irrigation season, and pro-rated flows by river mile from the Dunlap gage to the Acme gage to keep the river wet from Taiban to the mouth of Crockett Draw, which is located at the lower end of the upper critical habitat. The No Action Alternative also specifies targets at the Acme gage with the exception of dry irrigation condition targets, which only keep the critical habitat wet (just as in the critical habitat alternative). The pre-1991 baseline does not specify flow targets. Flow targets for all the alternatives are shown in Table 1.

The global assumption in the execution of the model is that all available CID supply used to achieve targeted river flows downstream of Sumner Dam is bypassed through the reservoir when available. Flow was not taken from CID storage to meet flow targets. This assumption stems from current operations and Reclamation's available latitude to bypass incoming flows through the reservoirs, but lack of authority to store the water in any of the reservoirs. Reclamation and CID jointly hold the right to divert and store river water for irrigation purposes. Bypass flows are those that Reclamation is simply not exercising its right to divert and store, with the understanding on CID's part that Reclamation will offset associated depletions with that bypass. For the modeling of NEPA alternatives, available bypass flow was evaluated on a daily basis.

Flow targets were modeled by inputting flow values into the model corresponding to the irrigation season and the hydrologic condition (wet, dry, or average). The irrigation season spans from March 1 through October 31 and throughout the NEPA process was sometimes interchanged with the word "summer". The non-irrigation season runs from November 1 to the end of February and was also sometimes interchanged with the word "winter".

The model computes hydrologic condition based on the method described in the current BO, which builds on the memorandum from Hydrosphere, detailing an approach for computing hydrologic condition using reservoir storage in the Lower Pecos Valley (Service, 2003; Hydrosphere, 2003d). It should be noted that previous memorandums, etc. referred to wet, dry, and average as hydrologic seasons, however, for clarification, the term hydrologic conditions is now employed.

In addition to flow targets, stipulations for block releases are modeled in all of the alternatives, including the No Action Alternative. The pre-1991 baseline does not have any stipulations on block releases. All of the alternatives include specifications of a 15-day maximum for block release duration and a frequency stipulation originally stated as, "space out as long as possible". This was later interpreted by the Biology Work Group as a minimum of 14 days in between releases. Additionally, all of the alternatives with the exception of the No Action Alternative also include the specification to "avoid release" for a 6-week period around August 1st. For modeling purposes, this stipulation was interpreted as a strict "no release" period from three weeks before to three weeks after August 1st.

The individual alternatives were modeled as follows:

- The Taiban Constant Alternative model has a constant flow target of 35 cfs at the Taiban gage for all hydrologic conditions and for both the irrigation season and the non-irrigation season.
- The Taiban Variable Alternative model consists of a constant non-irrigation season flow target of 35 cfs at the Taiban gage and variable irrigation season targets at the Taiban gage between 40 and 55 cfs. Due to the range of targets for this alternative, it was split into three sub alternative models including: a high range "summer" (HRS) target of 55 cfs, a mid-range "summer" (MRS) target of 45 cfs, and a low range "summer" (LRS) target of 40 cfs. The designation of "summer" for irrigation season targets is somewhat of a misnomer, but was carried through the analysis for consistency with the original alternative development process.
- The Acme Constant Alternative model has a constant flow target of 35 cfs at the Acme gage for all hydrologic conditions and for both the irrigation season and the non-irrigation season..
- The Acme Variable Alternative model consists of a constant non-irrigation season flow target at the Acme gage of 35 cfs and irrigation season flow targets of 12, 24, and 48 cfs for the respective dry, average, and wet hydrologic conditions.

- The Critical Habitat Alternative model contains a hybrid of flow targets because flow targets are specified at two gages. Non-irrigation season flow targets are specified as 35 cfs at the Taiban gage for all hydrologic conditions. Irrigation season targets for the average and wet seasons are 5 and 10 cfs, respectively at the Acme gage. For the dry hydrologic condition, during the irrigation season target, the alternative specifies keeping the critical habitat wet. This was modeled as a flow target of 0 cfs at the Acme Gage, corresponding to flow at Crocket Draw (the lower end of the upper critical habitat). The relationship between the two locations is dictated by season (winter, spring, summer and fall) as well as the distance from Dunlap to Crocket Draw and Crocket Draw to the Acme gage.
- The No Action Alternative has flow targets of 35 cfs at Acme in the non-irrigation season for all hydrologic conditions and flow targets of 20 cfs and 35 cfs for respective average and wet hydrologic conditions during the irrigation season. For the dry hydrologic condition, during the irrigation season target, the alternative specifies keeping the critical habitat wet. This was modeled as a flow target of 0 cfs at the Acme Gage, corresponding to flow at Crocket Draw (the lower end of the critical habitat).

It should be noted that the Critical Habitat and No Action alternatives have “designed intermittency” at the Acme gage for dry hydrologic conditions during the irrigation season. Since the upper critical habitat is *upstream* of the Acme gage, flow targets designed to only “keep the critical habitat wet,” result in intermittency at Acme.

Two criteria specified along with flow targets for some alternatives were not included in the models. The omissions are the Lynch Well pumping at Acme to prevent intermittency and the “minimum” stipulation tied to the non-irrigation targets at Taiban for the Critical Habitat Alternative. Modeling of the Lynch Well pumping at Acme was not included since this was considered to be an Additional Water Acquisition option, the effects of which aren’t covered in this memorandum. The 35 cfs “minimum” stipulation was not included for two reasons. The first reason is the model’s ability to meet targets on a ± 1 cfs basis is still subject to a total residual distribution on the order of 100 cfs. In order to truly meet the minimum statement as far as all modeling uncertainty is concerned, the target would have to be set unreasonably higher than 35 cfs. Secondly, since CID supply is not always available to be bypassed, the rigid “minimum” flow target would not be met anyway.

A fish conservation pool (FCP), to be used to augment bypass flows, was identified in the alternative development process. In addition to the modeling efforts for the alternative, quantities that would be needed for the FCP along with the potential impact to the flow exceedence curves by adding all of the additional water needed to the modeled Pecos River system are evaluated and presented in this report. Refer to the white paper by Hydrosphere et al. titled “Fish Conservation Pool Considerations for Carlsbad Project Water, Operations and Water Supply Conservation EIS” December, 2004.

Table 1. Baseline and Alternatives with Specified Flow Targets

Baseline or Alternative	Dry		Average		Wet	
	Non-irrigation Season Target (cfs)	Irrigation Season Target (cfs)	Non-irrigation Season Target (cfs)	Irrigation Season Target (cfs)	Non-irrigation Season Target (cfs)	Irrigation Season Target (cfs)
Taiban Constant	35 at Taiban	35 at Taiban[1]	35 at Taiban	35 at Taiban[1]	35 at Taiban	35 at Taiban[1]
Taiban Variable	35 at Taiban	40-55 at Taiban	35 at Taiban	40-55 at Taiban	35 at Taiban	40-55 at Taiban
Acme Constant	35 at Acme	35 at Acme	35 at Acme	35 at Acme	35 at Acme	35 at Acme
Acme Variable	35 at Acme	12 at Acme	35 at Acme	24 at Acme	35 at Acme	48 at Acme
Critical Habitat	35 at Taiban[2]	0 at Acme[3]	35 at Taiban[2]	5 at Acme	35 at Taiban[2]	10 at Acme
No Action	35 at Acme	0 at Acme[4]	35 at Acme	20 at Acme	35 at Acme	35 at Acme
Pre-1991 Baseline	N/A	N/A	N/A	N/A	N/A	N/A

[1] Use pumps to avoid intermittency at Acme.
[2] Specified as “minimum”.
[3] Critical Habitat Kept Wet; Avoid Intermittency at Acme.
[4] Upper Critical Habitat Kept Wet; Avoid Intermittency at Acme.

The remainder of this memorandum documents the results and interpretations for the modeled alternatives, as compared to the pre-1991 baseline where appropriate.

3.0 Results

Flow exceedance curves at Taiban and Acme, comparisons of those modeled flow durations, net depletions to CID supply, net depletions to flows at the state line, and water accounting for bypasses and additional water needs for each of the alternatives are presented in sections 3.1 through 3.5.

3.1 Flow Exceedance Curves

Flow exceedance curves for each of the alternatives are shown in this section. The curves represent the amount of time (shown on the x-axis) that the discharge (shown on the y-axis) is met or exceeded. Note that the flow values for the entire model analysis (60 years of values, 365 days per year, and 366 days in leap years) were used in the calculations performed for creating the curves.

For example, in Figure 1, 70% of the time, the flow at the Taiban gage is approximately 37 cfs or more based on model results of the pre-1991 baseline, and 50 cfs or more based on the model results for the No Action Alternative.

Comparing the alternatives to the pre-1991 baseline allows the reader to determine if the alternative acts to increase or decrease the percent of time the flows are met or exceeded. In most cases, the alternatives increase the flows in the lower ranges of the discharge, typically in the vicinity of the flow target, and correspondingly decrease the flows in the upper ranges of the discharges, in the block release (1,000-1,200 cfs) range. The discharge of the y-axis is plotted on a log scale to allow the reader to view the entire range of flows while still allowing for some detail to be observed in the lower ranges.

The results of the analysis for the hypothetical case that all of the additional water needs (AWN) can be met are also included on the graphs as “with all AWN added”. It is important to note that in modeling river flow with AWN, the water added to the system is assumed to be non-project water. The importance of this assumption is that if the water was analyzed as CID water, the flow frequency curve would be affected in a different manner. If the water is taken from CID supply, the amount available for block releases decreases additionally to the decrease already caused by bypassing. Since AWN was modeled as water input from “outside” the system, the change in flow durations is only evident in the low flow range. In other words the water wasn’t taken from one portion of the curve and distributed into another, as is the case with the bypass modeling.

For ease of comparison, all of the alternative model results at the Taiban gage are presented in Figures 1 through 8 with all of the results at the Acme gage presented in Figures 9 through 16. Modeled intermittency statistics at the Acme Gage are presented in Tables 2 through 4. Table 2 presents bypass intermittency statistics with intermittency at Acme defined as zero cubic-feet per second. Table 3 also presents bypass intermittency statistics at Acme, but with intermittency defined as flows less than or equal to 1.6 cubic-feet per second. Table 4 presents intermittency statistics using non-project water to supply a fish conservation pool, with intermittency defined as zero cubic feet per second at Acme. Figure 17 is a graphical depiction of Tables 2 and 3.

Figure 1. Flow Frequency at the Taiban Node –No Action Alternative

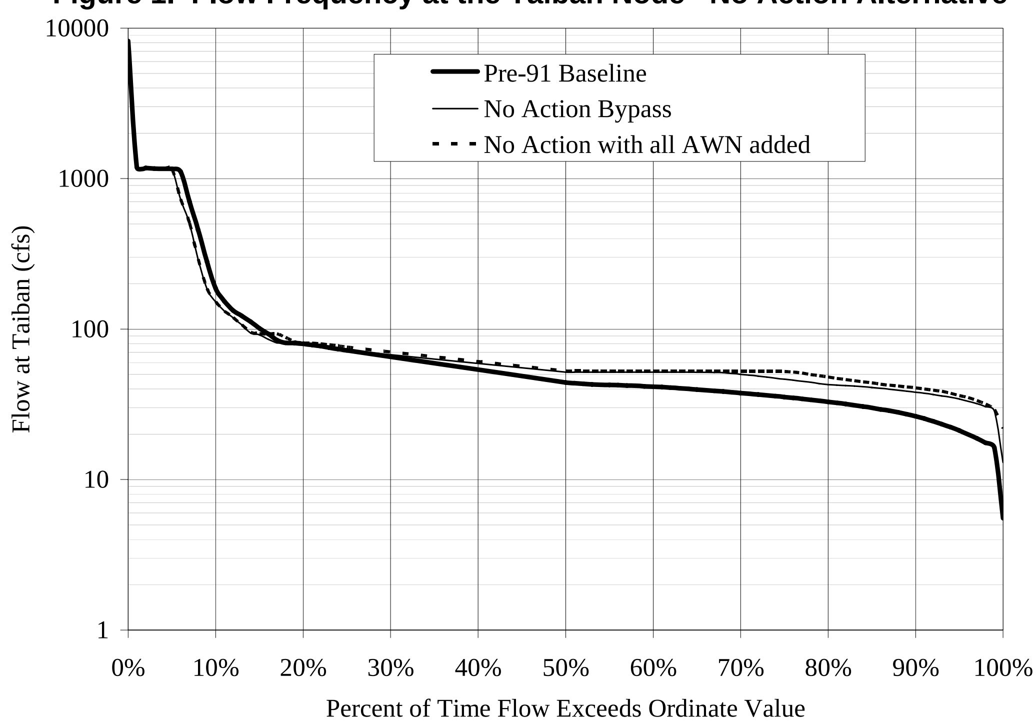


Figure 2. Flow Frequency at the Taiban Node – Taiban Constant Alternative

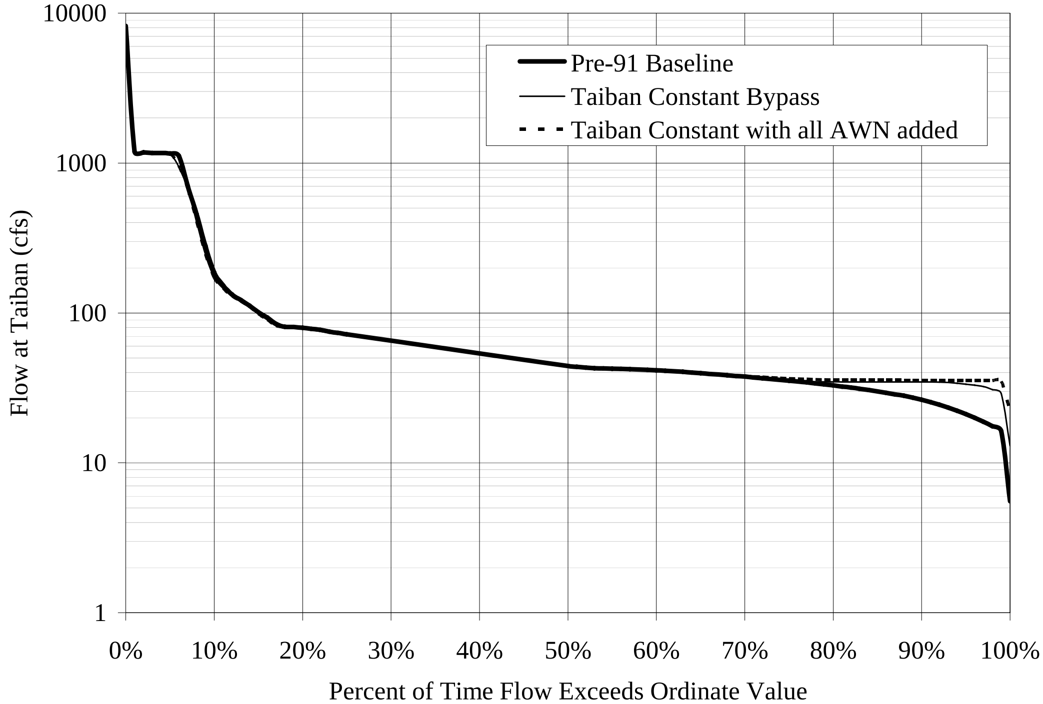


Figure 3. Flow Frequency at the Taiban Node – Taiban Variable HRS (55 cfs) Alternative

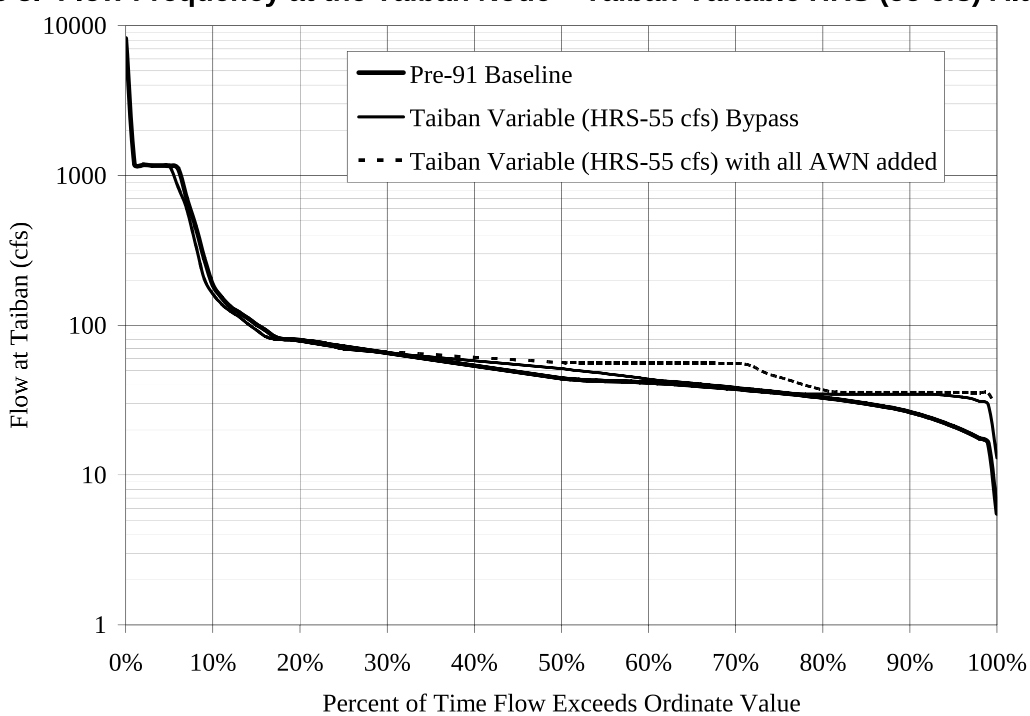


Figure 4. Flow Frequency at the Taiban Node – Taiban Variable MRS (45cfs) Alternative

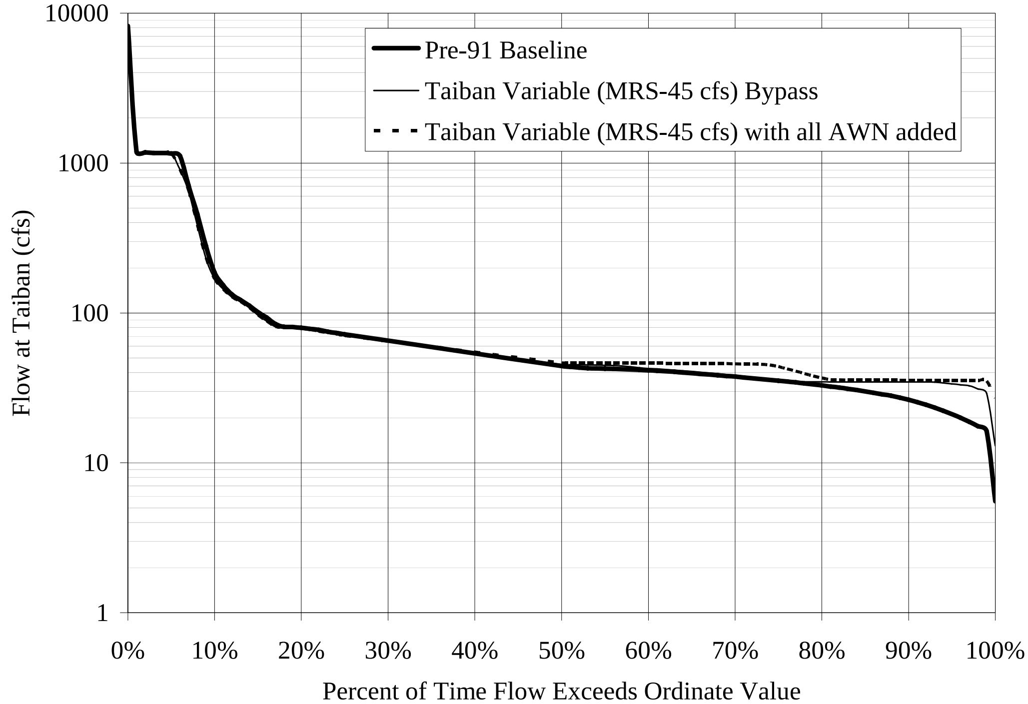


Figure 5. Flow Frequency at the Taiban Node – Taiban Variable LRS (40cfs) Alternative

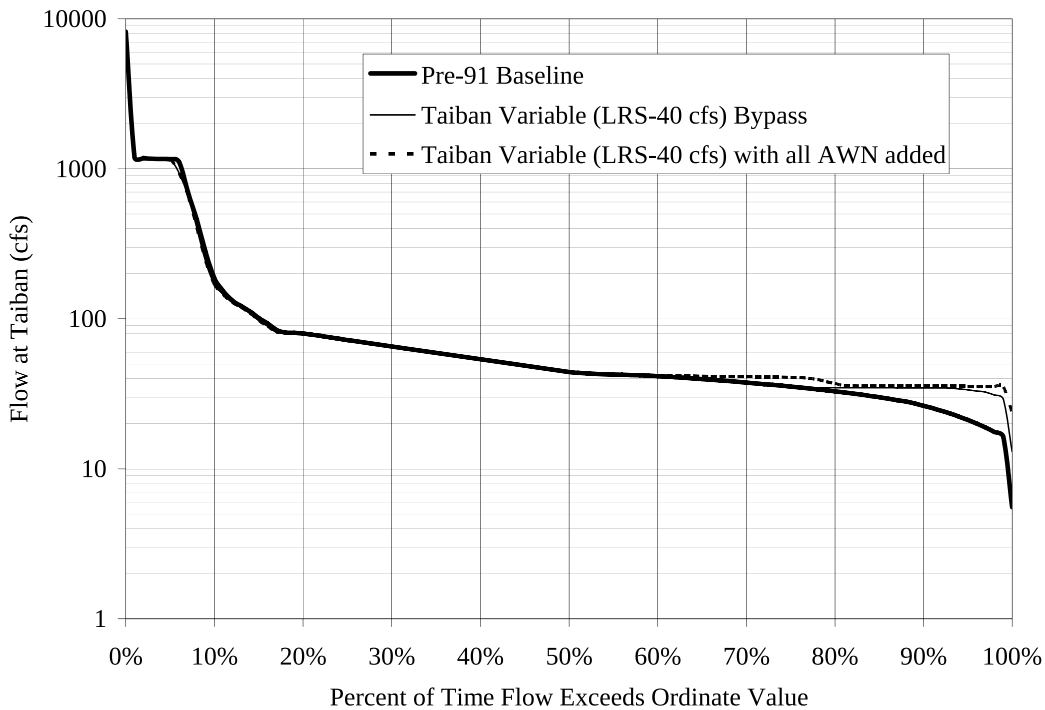


Figure 6. Flow Frequency at the Taiban Node – Acme Constant Alternative

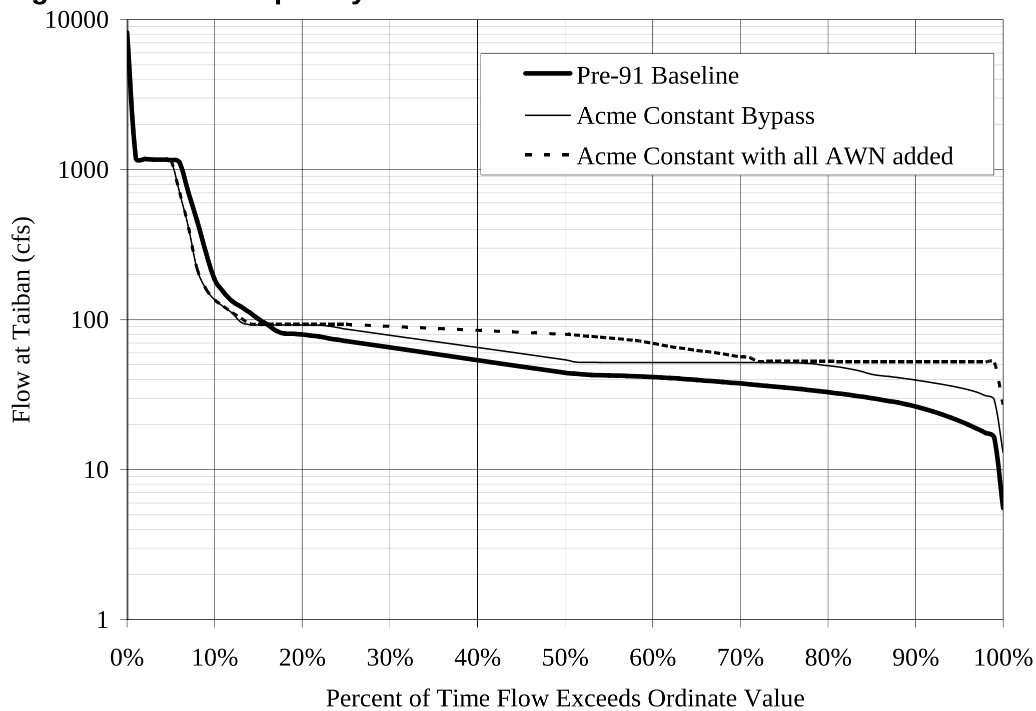


Figure 7. Flow Frequency at the Taiban Node – Acme Variable Alternative

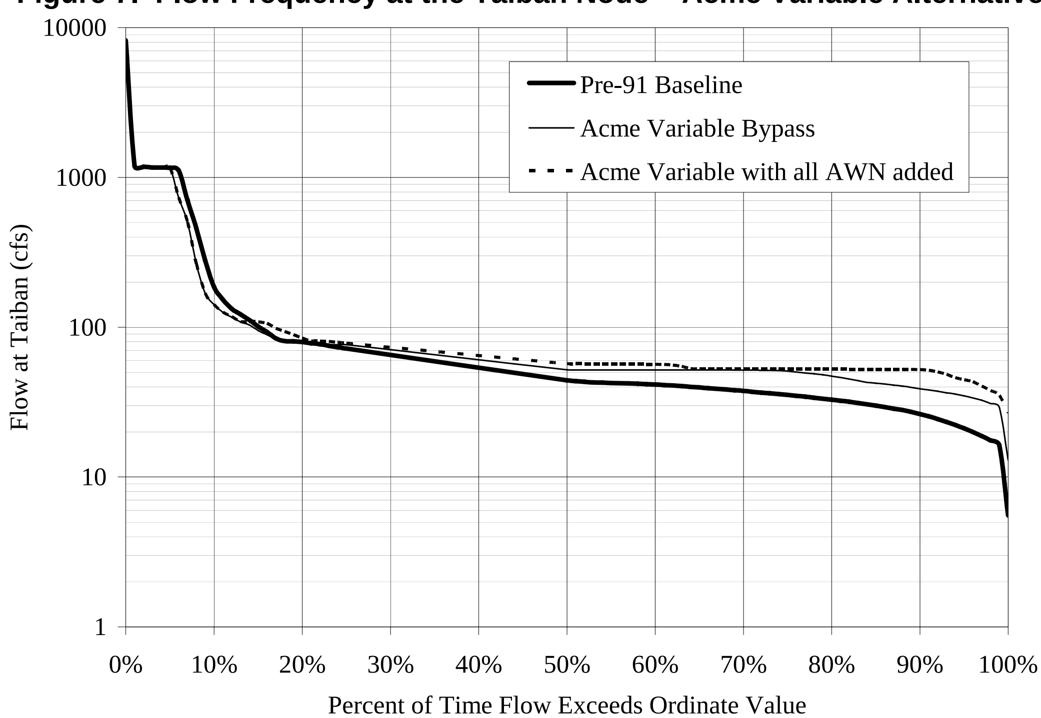


Figure 8. Flow Frequency at the Taiban Node – Critical Habitat Alternative

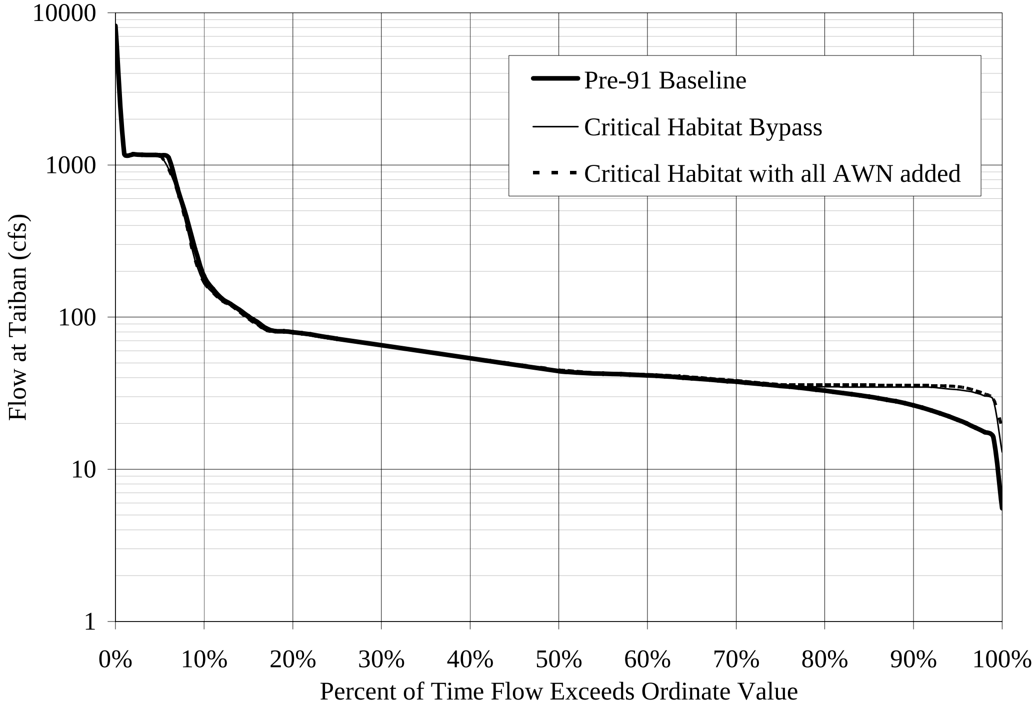


Figure 9. Flow Frequency at the Acme Node –No Action Alternative

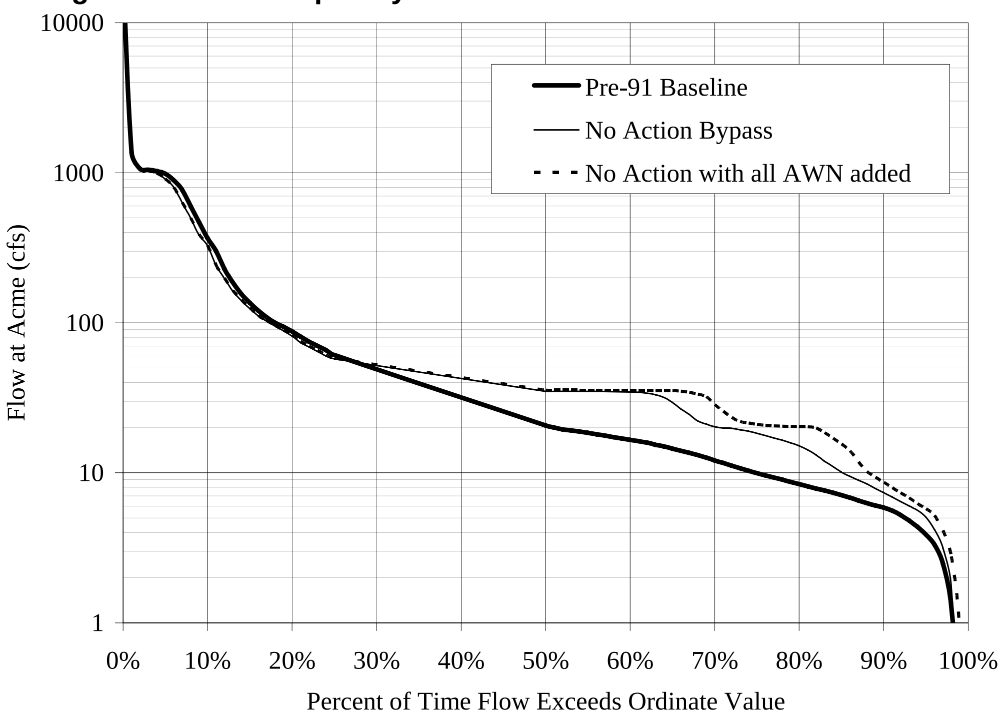


Figure 10. Flow Frequency at the Acme Node – Taiban Constant Alternative

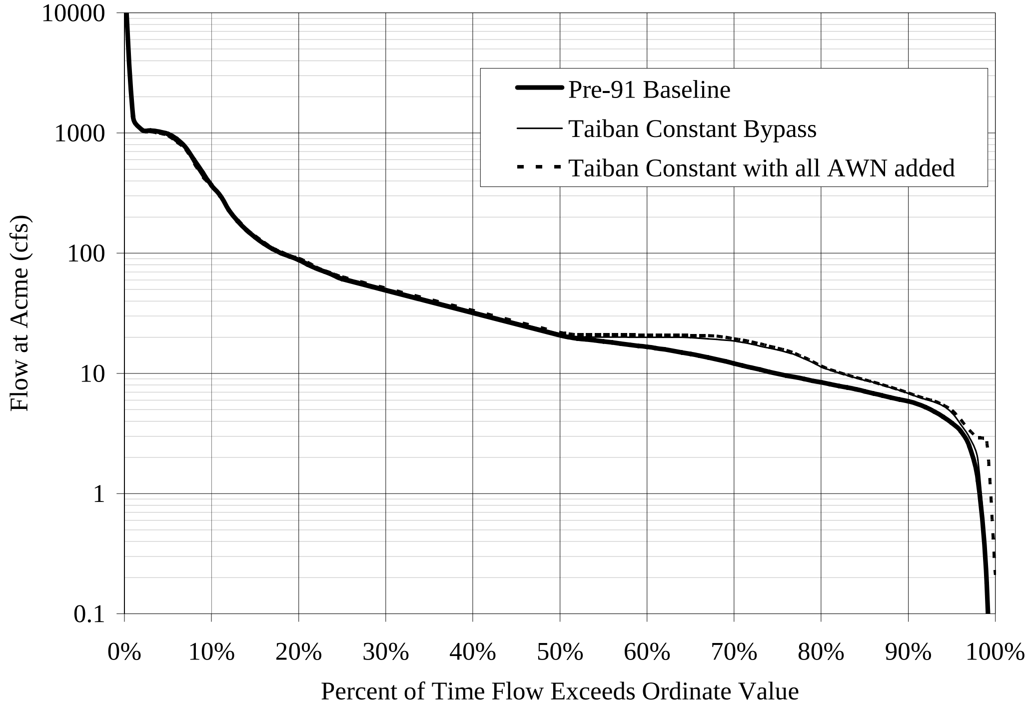


Figure 11. Flow Frequency at the Acme Node – Taiban Variable HRS (55cfs) Alternative

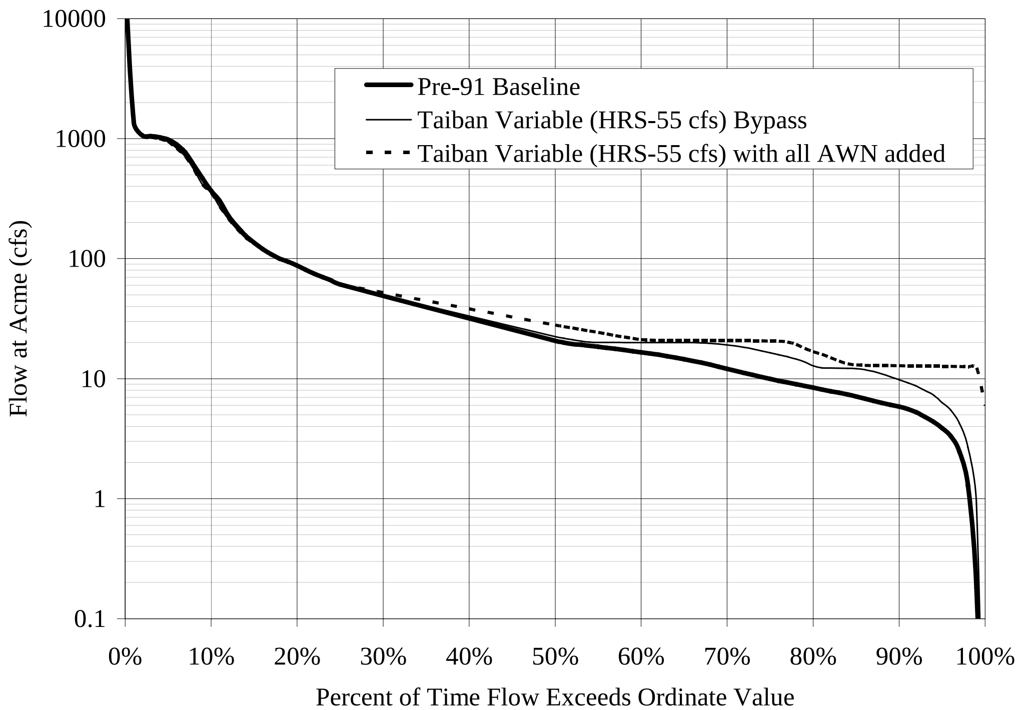


Figure 12. Flow Frequency at the Acme Node – Taiban Variable MRS (45cfs) Alternative

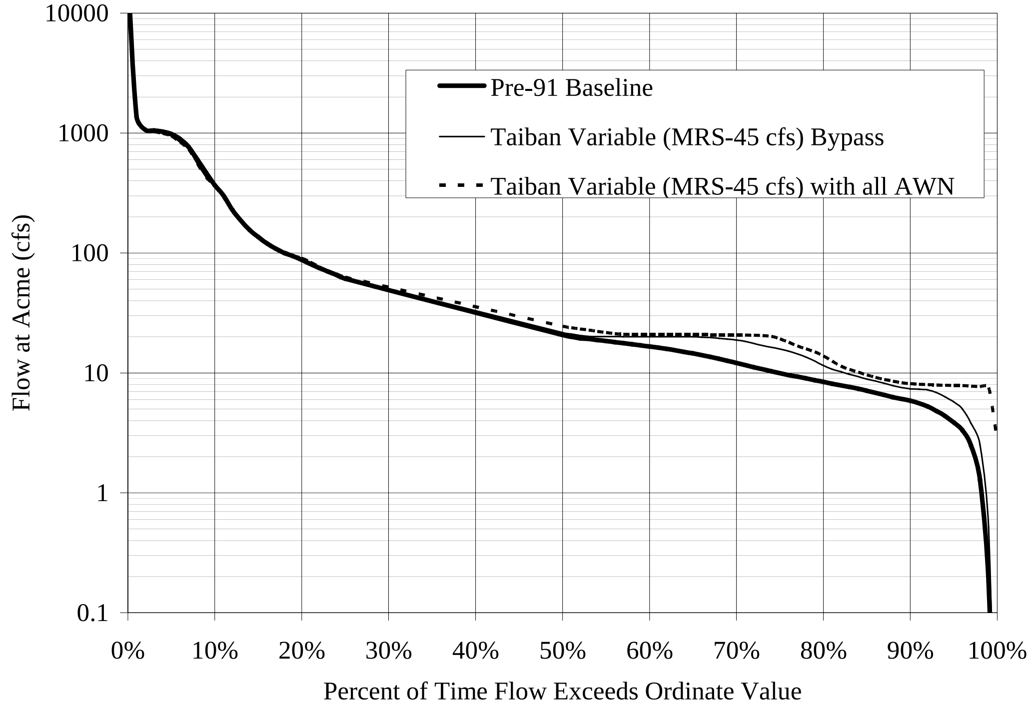


Figure 13. Flow Frequency at the Acme Node – Taiban Variable LRS Alternative

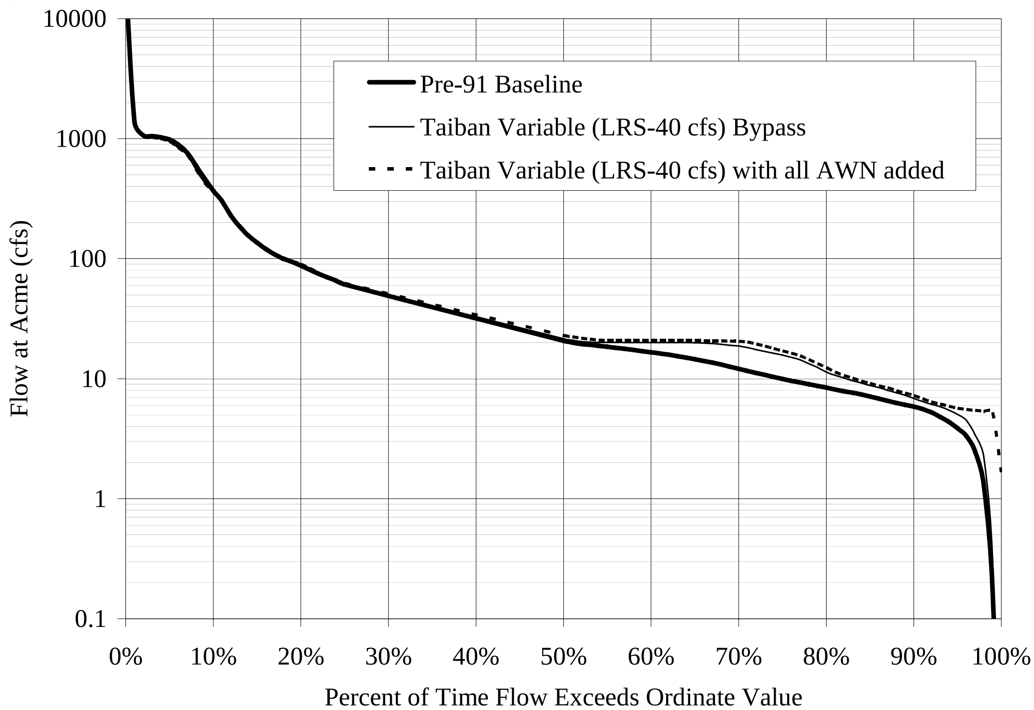


Figure 14. Flow Frequency at the Acme Node – Acme Constant Alternative

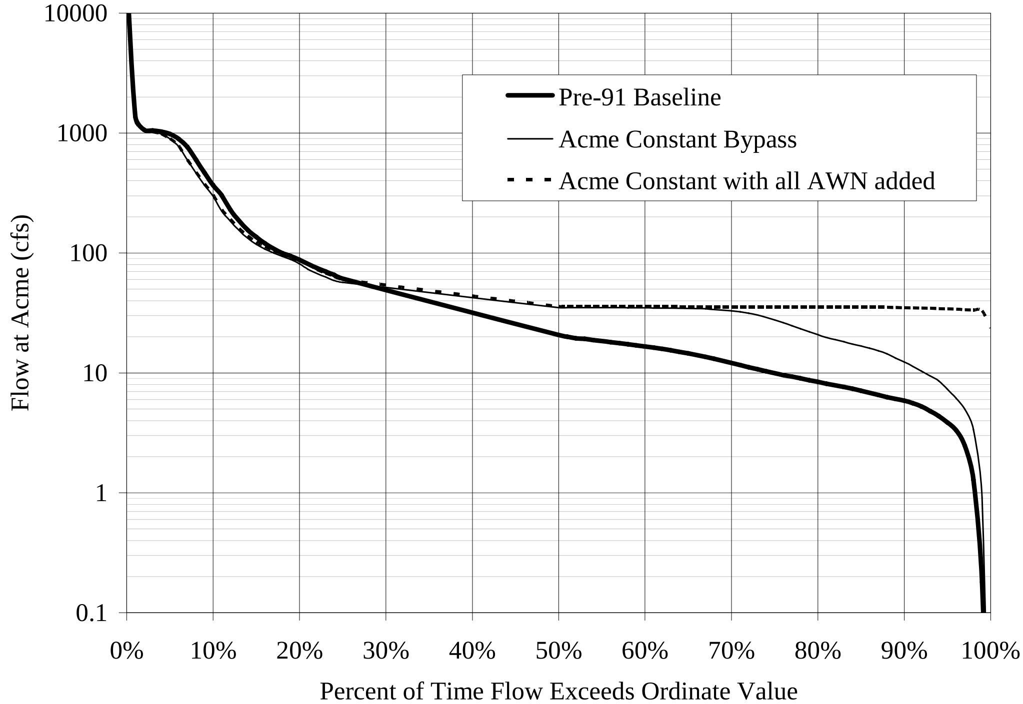


Figure 15. Flow Frequency at the Acme Node – Acme Variable Alternative

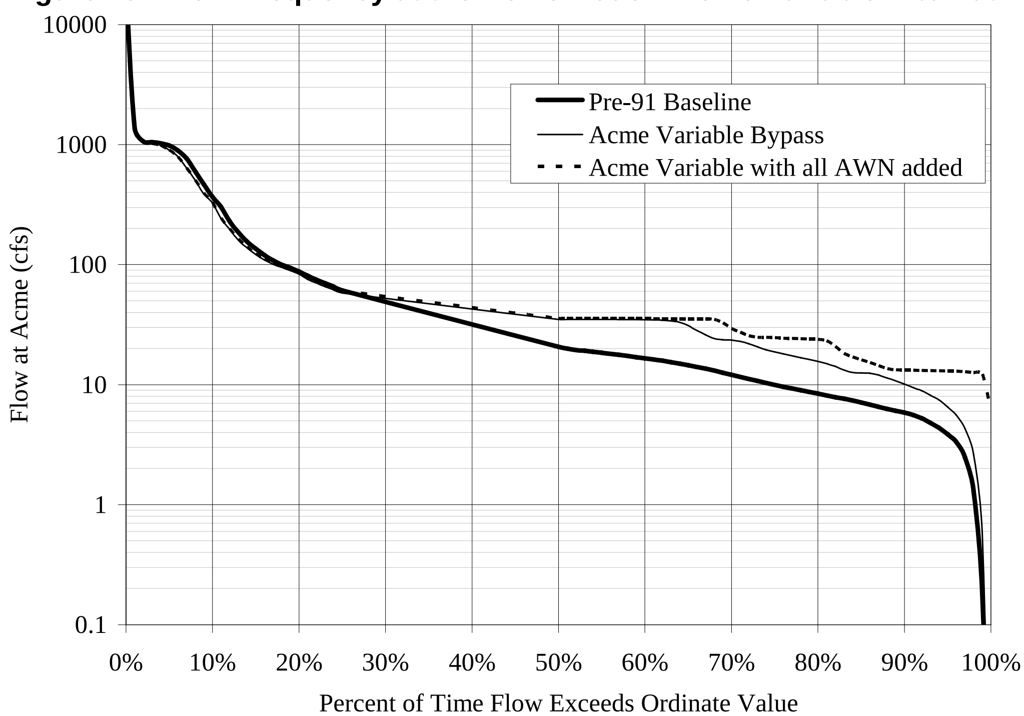


Figure 16. Flow Frequency at the Acme Node – Critical Habitat Alternative

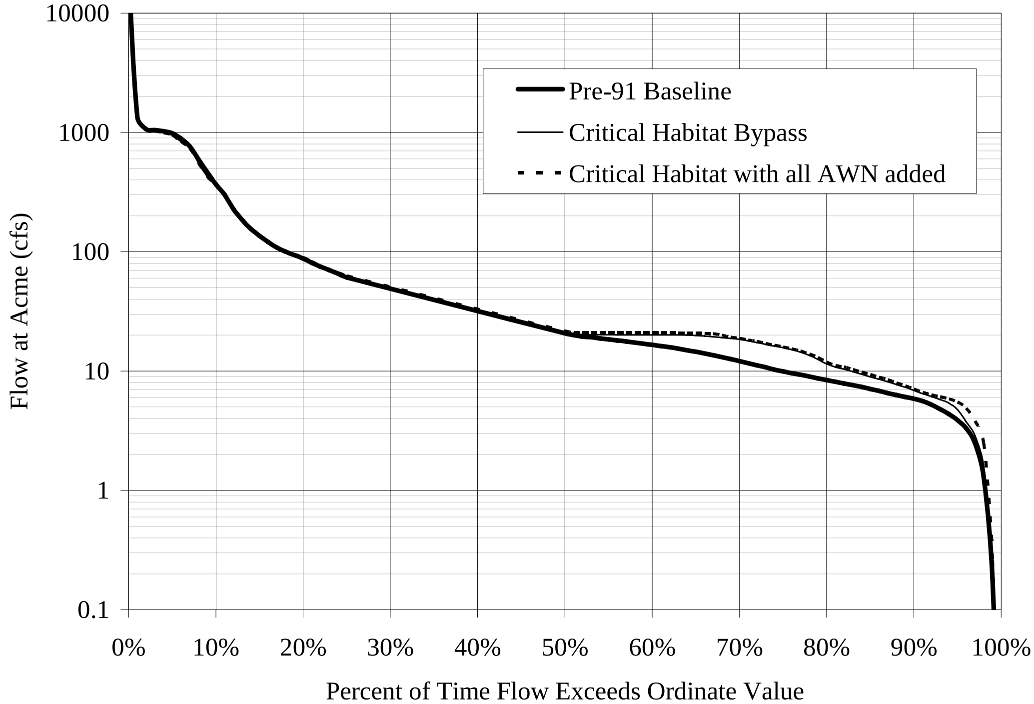


Table 2. Bypass and Block Release Reoperations—Intermittency Statistics for the Alternatives and the Pre-1991 Baseline

Acme Intermittency Statistics
(Intermittency defined as less than or equal to **0.0** cfs)

	No Action w/ 6-Week	No Action wo/ 6-Week	Pre-1991 Baseline	Taiban Constant	Taiban Variable (HRS-55 cfs)	Taiban Variable (LRS-40 cfs)	Taiban Variable (MRS-45 cfs)	Acme Constant	Acme Variable	Critical Habitat
Percent of Time Intermittent	0.9	0.9	1.2	0.9	0.6	0.8	0.8	0.7	0.7	1.1
Total No. of Intermittent Days	193	205	263	196	137	187	176	147	150	234
Total No. of Days in Run	21,915	21,915	21,915	21,915	21,915	21,915	21,915	21,915	21,915	21,915
Periods of Intermittency: Single or Consecutively Intermittent Days										
1 day	3	1	4	6	1	2	1	3	4	2
2 to 5 days	9	10	8	5	4	6	5	2	3	10
6 to 10 days	8	5	9	6	6	5	7	5	5	8
11 to 20 days	4	2	3	2	3	2	2	2	3	3
21 to 30 days	2	3	5	4	1	4	3	3	2	4
> 30 days	0	1	0	0	0	0	0	0	0	0

Table 3. Bypass and Block Release Reoperations—Intermittency Statistics for the Alternatives and the Pre-1991 Baseline

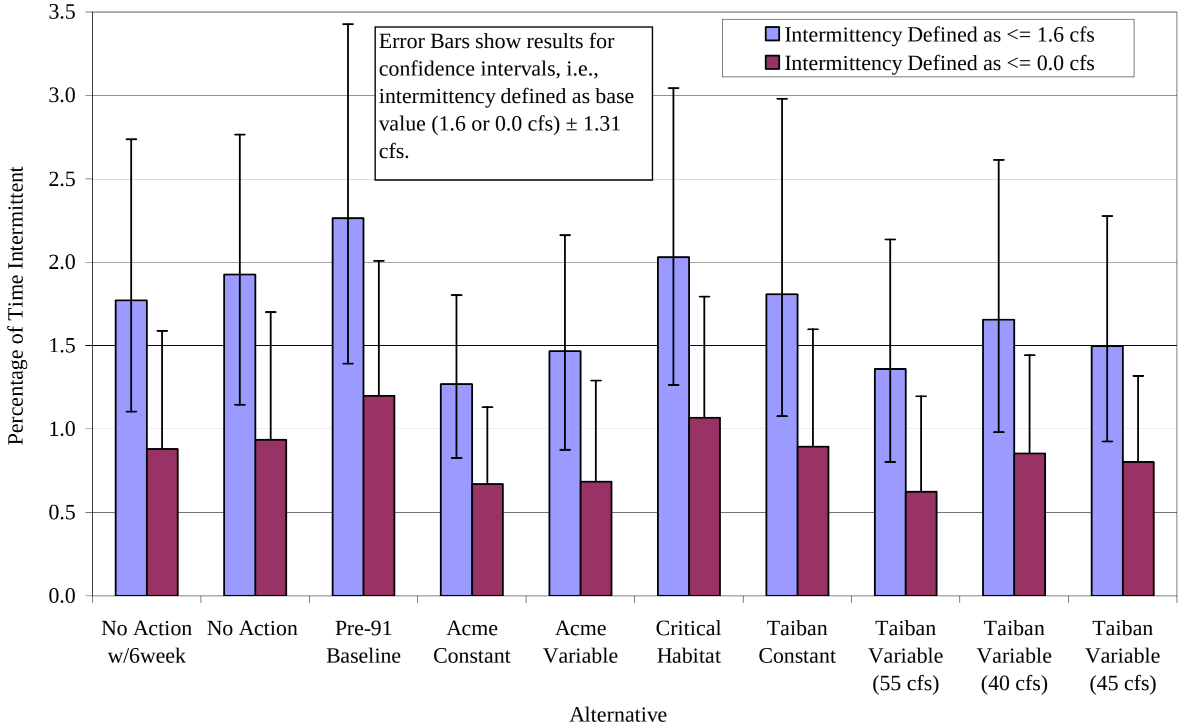
Acme Intermittency Statistics
(Intermittency defined as less than or equal to **1.6** cfs)

	No Action w/ 6-Week	No Action wo/ 6-Week	Pre-1991 Baseline	Taiban Constant	Taiban Variable (HRS-55 cfs)	Taiban Variable (LRS-40 cfs)	Taiban Variable (MRS-45 cfs)	Acme Constant	Acme Variable	Critical Habitat
Percent of Time Intermittent	1.8	1.9	2.3	1.8	1.4	1.7	1.5	1.3	1.5	2.0
Total No. of Intermittent Days	388	422	496	396	298	363	328	278	321	445
Total No. of Days in Run	21,915	21,915	21,915	21,915	21,915	21,915	21,915	21,915	21,915	21,915
Periods of Intermittency: Single or Consecutively Intermittent Days										
1 day	9	8	9	9	7	9	8	5	8	10
2 to 5 days	16	16	15	15	8	14	11	11	10	17
6 to 10 days	11	14	14	8	9	10	9	7	9	13
11 to 20 days	6	4	9	8	6	5	5	3	3	7
21 to 30 days	4	4	5	3	2	3	3	4	5	4
> 30 days	1	2	2	2	1	2	2	1	1	2

Table 4. Bypass with All Additional Water Needs Added to Sumner Outflow—Intermittency Statistics for the Alternatives and the Pre-1991 Baseline

Acme Intermittency Statistics (Intermittency defined as less than or equal to **0.0** cfs)										
	No Action w/ 6-Week	**No Action wo/ 6-Week**	**Pre-1991 Baseline**	**Taiban Constant**	**Taiban Variable (HRS-55 cfs)**	**Taiban Variable (LRS-40 cfs)**	**Taiban Variable (MRS-45 cfs)**	**Acme Constant**	**Acme Variable**	**Critical Habitat**
Percent of Time Intermittent	0.7	0.7	1.2	0	0	0	0	0	0	0.8
Total No. of Intermittent Days	158	263	0	0	0	0	0	0	0	187
Total No. of Days in Run	21,915	21,915	21,915	21,915	21,915	21,915	21,915	21,915	21,915	21,915
Periods of Intermittency: Single or Consecutively Intermittent Days										
1 day	1	1	4	0	0	0	0	0	0	2
2 to 5 days	10	10	8	0	0	0	0	0	0	9
6 to 10 days	7	4	9	0	0	0	0	0	0	7
11 to 20 days	3	3	3	0	0	0	0	0	0	2
21 to 30 days	1	2	5	0	0	0	0	0	0	3
> 30 days	0	0	0	0	0	0	0	0	0	0

Figure 17. Acme Percentage of Time Intermittent (99% Confidence Intervals Results Are Included as Error Bars)



3.2 Alternative Comparisons – Flow Frequency and Intermittency

Table 5 presents flows exceeding 1, 25, 50, 75, and 100 percent of the total flow record for the given alternative or baseline at the Puerto de Luna, Taiban, Dunlap, Acme, Artesia, and Kaiser model nodes. For example, the flow at the Puerto de Luna Node is greater than or equal to 96 cfs 25% of the time under the Taiban Constant Alternative.

Nodes at Hagerman and Lake Arthur are not presented since the final flow frequency curves were not modified to account for the spatial distribution of accumulating base inflows in this reach. Base inflows are lumped together at the Artesia node in the model, and for this reason the Artesia and Kaiser nodes were included.

Table 5
Flow Frequency at Selected Model Nodes

Percent of Time Flow is Greater Than:	No Action w/ 6-Week	No Action wo/ 6-Week	Taiban Const.	Taiban Var. (HRS-55 cfs)	Taiban Var. (LRS-40 cfs)	Taiban Var. (MRS-45 cfs)	Acme Const.	Acme Var.	Crit. Hab.	Pre-91
	Flow at the Puerto de Luna Node (cfs)									
1%	1416	1397	1400	1414	1400	1413	1405	1400	1400	1431
25%	96	96	96	95	96	95	95	95	95	96
50%	77	77	77	77	77	77	77	77	77	77
75%	65	65	65	65	65	65	65	65	65	64
100%	6	6	6	6	6	6	13	6	6	6
	Flow at the Taiban Node (cfs)									
1%	1183	1184	1182	1187	1183	1184	1183	1185	1182	1188
25%	73	72	72	69	71	71	86	76	71	72
50%	52	52	44	51	44	45	54	52	44	44
75%	46	46	36	36	36	36	52	51	35	35
100%	13	13	13	13	13	13	13	13	13	6
	Flow at the Dunlap Node (cfs)									
1%	1142	1145	1143	1144	1144	1143	1142	1142	1144	1149
25%	64	64	65	63	65	64	70	66	65	65
50%	47	47	33	37	33	33	47	47	33	33
75%	33	33	30	30	30	30	46	37	30	26
100%	8	8	8	8	8	8	8	8	8	1
	Flow at the Acme Node (cfs)									
1%	1294	1362	1316	1312	1317	1315	1287	1307	1316	1370
25%	59	57	63	60	62	62	57	58	63	61
50%	35	35	21	22	22	22	35	35	21	21
75%	18	18	16	16	16	16	28	19	16	10
100%	0	0	0	0	0	0	0	0	0	0
	Flow at the Artesia Node (cfs)									
1%	1524	1553	1546	1549	1546	1540	1479	1528	1546	1585
25%	131	128	132	130	132	132	128	130	132	129
50%	84	83	76	76	76	76	84	84	76	73
75%	53	51	51	52	51	51	57	53	51	46
100%	6	6	6	6	6	6	6	6	6	6
	Flow at the Kaiser Node (cfs)									
1%	1562	1592	1606	1584	1610	1601	1546	1554	1610	1625
25%	127	123	129	126	128	128	123	125	128	125
50%	79	78	71	71	71	71	79	79	71	68
75%	48	46	47	47	47	47	51	48	46	42
100%	2	2	2	2	2	2	2	2	2	2

Observations concerning bypass flow frequency include:

- No alternative or baseline prevents intermittency entirely at Acme when only bypass operations are considered.
- Percent of intermittency is generally related to bypass flow targets: higher flow targets have lower intermittency, but the change percent is not that significant among all the alternatives.
- Only No Action and Critical Habitat show intermittency with unlimited water supply to meet all of the AWN; however, these two alternatives were designed to be intermittent in dry times.
- The Acme Constant Alternative shows a considerably higher flow (~10cfs), for the 75th percentile at the Acme node, than all of the other alternatives or the pre-1991 baseline.
- Even though the Acme Constant Alternative targets 35 cfs at Acme, due to the shortage of incoming supply, this alternative is only able to maintain this flow in the Pecos River 50% of the time.
- The Taiban Variable and Taiban Constant Alternatives show very little flow frequency difference at the Taiban and Acme nodes for the 75th and 100th percentile once again indicating the limitation of supply, and especially during dry times.
- Flows for equal percentiles at the Artesia gage and Kaiser gage are very similar for all of the alternatives and the baseline indicating that flow targets have little bearing on flow frequency in the Pecos River downstream of base inflows occurring in the Acme to Artesia reach.

3.3 Net Depletions to the Carlsbad Project Supply

Net depletions to Carlsbad Project supply and to State-line flows were computed by subtracting the change over time of the output parameter in question (storage and diversions for CID, flows at Red Bluff for the state line) for an alternative from the same parameter, over the same length of time, for the pre-1991 baseline. This section defines many components of net depletions with equations and explains their relative importance in this EIS and also explains the limitations of the interpretations of output data with these types of comparisons. In addition, annual average net depletion results for the alternatives are presented at the end of the section along with maximum and minimum annual transmission depletions between Sumner Reservoir and Brantley Reservoir due to bypassing.

Calculations for Net Depletions

The annual values computed with the equations presented in this section were sometimes presented discretely, but were typically averaged to show a trend. This average can be rather informative about the long term effects of operations on water supply over the 60-year modeling period. Through the development of modeling interpretations, several problems were discovered with the use of these equations for estimating annual net depletions to CID. At first attempts were made to correct the annual values (See Eq. 3.3.), but eventually the annual terms were found to contain annual variables that could skew the annual net depletion values on the order of 1,000’s of acre-feet (See Erroneous Net Depletions further in this section.). For this reason only 60-year averages are presented when using the equations in this section. Definitions for net depletion terms and equations used in this memorandum are summarized in bulleted format below.

- Total net depletions to CID: the total net depletion to CID is computed using the change in Effective Brantley Storage (Tetra Tech, 2000b) and diversions at the CID main canal. Annual total net depletions to CID are computed using Equation 3.1. Note that negative values computed with this equation would indicate an *accretion* to CID.

$$\begin{array}{l}\textit{Annual} \\ \textit{Net Depletion} \\ \textit{to CID}\end{array} = \begin{array}{l}\textit{No Action Annual} \\ \textit{Change in Eff.} \\ \textit{Brantley Storage}\end{array} - \begin{array}{l}\textit{Action Annual} \\ \textit{Change in Eff.} \\ \textit{Brantley Storage}\end{array} + \begin{array}{l}\textit{No Action CID} \\ \textit{Annual Diversion} \\ \textit{Volume}\end{array} - \begin{array}{l}\textit{Action CID} \\ \textit{Annual Diversion} \\ \textit{Volume}\end{array} \qquad \text{(Eq. 3.1)}$$

- Net depletions at the CID main: net depletions to CID considering only diversions from Avalon Dam made by CID. Equation 3.1 can be used with the Effective Brantley Storage terms removed.

- Net depletions to Effective Brantley Storage: net depletions to CID storage normalized as if all of the water were present in Brantley or Avalon Reservoirs. Eq 3.1 can be used with the diversion volume terms removed.

- Annual net depletions to Avalon spills: the decrease of spills from Avalon dam. Eq. 3.2 can be used to compute net depletions to Avalon spills.

$$\begin{array}{l}\textit{Net Depletion} \\ \textit{to Avalon Spills}\end{array} = \begin{array}{l}\textit{No Action} \\ \textit{Avalon Spills}\end{array} - \begin{array}{l}\textit{Action} \\ \textit{Avalon Spills}\end{array} \qquad \text{(Eq. 3.2)}$$

- Corrected reoperation net depletions to CID: the total net depletion to CID with year-to-year spill variabilities removed from the net depletions, but with the long-term spill trend contribution to the net depletions added back (Tetra Tech, 2003e). Corrected reoperation net depletions are computed using Equation 3.3.

$$\begin{array}{l}\textit{Corrected Net} \\ \textit{Depletions to Carlsbad} \\ \textit{Supply due to} \\ \textit{Reoperation}\end{array} = \begin{array}{l}\textit{Total Net} \\ \textit{Depletions} \\ \textit{to Carlsbad} \\ \textit{Supply}\end{array} + \begin{array}{l}\textit{Net Depletions} \\ \textit{to Avalon} \\ \textit{Spills}\end{array} - \begin{array}{l}\textit{60 - year Average} \\ \textit{Net Depletion} \\ \textit{to Avalon} \\ \textit{Spills}\end{array} \qquad \text{(Eq. 3.3)}$$

- Reoperation net depletions to CID: the total net depletion to CID with all the effects of the spills removed. Equation 3.4 computes the reoperation net depletions to CID.

$$\begin{array}{l}\textit{Net Depletions} \\ \textit{to Carlsbad Supply} \\ \textit{due to Reoperations}\end{array} = \begin{array}{l}\textit{Total Net} \\ \textit{Depletions} \\ \textit{to Carlsbad Supply}\end{array} + \begin{array}{l}\textit{Net Depletions} \\ \textit{to Avalon Spills}\end{array} \qquad \text{(Eq. 3.4)}$$

Up to this point, net depletion results are presented by using the change in storage and the change in diversions measured at the CID main to predict total changes in CID operations. Consider Equation 3.5, which is the mass balance equation for reservoirs. The left side of the equation represents the sum total of operations as defined by the right side of the equation. Equation 3.5 can be expanded and combined with net depletion terminology to develop Equation 3.6.

- The storage mass balance equation is shown below as Equation 3.5.

$$\Delta Storage = Inflow - Outflow \qquad \text{(Eq. 3.5)}$$

- The relationship between net depletions to storage, inflow, and outflow is shown below as Equation 3.6.

$$Net\ Depletion\ to\ \Delta Storage = Net\ Depletion\ to\ Inflow - Net\ Depletion\ to\ Outflow \qquad \text{(Eq. 3.6)}$$

- Recognizing that outflow takes many forms and expanding terms generates Equation 3.7, which can be used for any reservoir.

$$\begin{aligned} \underset{to\ \Delta Storage}{Net\ Depletion} &= \underset{to\ Inflow}{Net\ Depletion} - \underset{to\ Outflow}{Net\ Depletion} - \underset{to\ Evaporation}{Net\ Depletion} - \underset{to\ Diversion}{Net\ Depletion} \\ &\quad - \underset{to\ \Delta\ in\ Res.Bank\ Stor}{Net\ Depletion} - \underset{Reservoir\ Seepage}{Net\ Depletion\ to} \end{aligned} \qquad \text{(Eq. 3.7)}$$

- Next, additional transmission depletions for a specific reach can be calculated by combining coefficients for Effective Brantley Storage with inflow and outflow terms for adjacent reservoirs from the right hand side of Eq. 3.7. It would follow that the additional transmission loss would be equal to the shortage of incoming water at the downstream reservoir (net depletions to inflows) plus the additional amount released from the upstream reservoir (net accretion to outflow = -net depletion to outflow). Using the preceding logic and coefficients for Effective Brantley Storage, Equations 3.8, 3.9, and 3.10 calculate additional transmission losses (normalized to Brantley storages) for the Santa Rosa Reservoir to Sumner Reservoir, Sumner Reservoir to Brantley Reservoir, and Brantley Reservoir to Avalon Reservoir, river reaches, respectively.

$$\begin{aligned} \underset{From\ Santa\ Rosa\ to\ Sumner}{Additional\ Transmission\ Loss} &= 0.75 * \underset{At\ Sumner\ Reservoir}{Net\ Depletions\ to\ Inflows} \\ &\quad - 0.65 * \underset{At\ Santa\ Rosa\ Reservoir}{Net\ Depletions\ to\ Outflows} \end{aligned} \qquad \text{(Eq. 3.8)}$$

$$\begin{aligned} \underset{From\ Sumner\ to\ Brantley}{Additional\ Transmission\ Loss} &= \underset{At\ Brantley\ Reservoir}{Net\ Depletions\ to\ Inflows} \\ &\quad - 0.75 * \underset{At\ Sumner\ Reservoir}{Net\ Depletions\ to\ Outflows} \end{aligned} \qquad \text{(Eq. 3.9)}$$

$$\begin{aligned} \underset{From\ Brantley\ to\ Avalon}{Additional\ Transmission\ Loss} &= \underset{At\ Avalon\ Reservoir}{Net\ Depletions\ to\ Inflows} \\ &\quad - \underset{At\ Brantley\ Reservoir}{Net\ Depletions\ to\ Outflows} \end{aligned} \qquad \text{(Eq. 3.10)}$$

Total additional transmission losses (normalized to Brantley storages) are equal to the sum of the three preceding equations.

- Similarly, total saved evaporation can be computed by combining the net depletions to evaporation at every reservoir with the Effective Brantley Storage coefficients. This is presented as Equation 3.11.

$$\begin{aligned}\textit{Saved Reservoir Evaporation} = {} & 0.65 * \textit{Net Depletions to Santa Rosa Evap} + 0.75 * \textit{Net Depletions to Sumner Evap} \\ & + \textit{Net Depletions to Brantley Evap} + \textit{Net Depletions to Avalon Evap}\end{aligned} \qquad \text{(Eq. 3.11)}$$

Equations 3.10 and 3.11 can be combined with the unused terms of Equation 3.7 (net depletions to seepage at Avalon and net depletions to bank storage at Brantley) to calculate the same result for corrected reoperation net depletions as Equation 3.3.

60-year Average Results Using Net Depletion Mass Balance

60-year average net depletion results are presented here. Tables 6-9 show net depletion mass balances for the respective reservoirs: Santa Rosa, Sumner, Brantley, and Avalon. The net depletions in these tables are not normalized to Effective Brantley Storage and all of the columns (net depletion components) in each table sum to zero. Table 10 shows additional transmission (reach) losses due to the alternatives (sum of Equations 3.8 through 3.10). Table 11 shows saved evaporation normalized to Effective Brantley Storage (Eq. 3.11). Table 12 presents 60-year average corrected reoperation net depletions (includes long-term spill trend) to CID for all the alternatives and Table 13 presents 60-year average reoperation net depletions to CID (excludes spills completely).

Table 6. Net Depletion Mass Balance for Santa Rosa Reservoir

Alternative	**60-year average (acre-feet per year)**			
	Net Depletion to Inflow	Net Depletion to Outflow	Net Depletion to Evaporation	Net Depletion to Change in Storage
Acme Constant	0	-522	618	-96
Acme Variable	0	-299	395	-96
Critical Habitat	0	4	93	-96
Taiban Constant	0	16	80	-96
Taiban Variable LRS	0	-10	106	-96
Taiban Variable MRS	0	-64	160	-96
Taiban Variable HRS	0	-137	233	-96
No Action	0	229	-133	-96

Table 6 shows that Carlsbad Project reoperations modeling indicates evaporation will be saved at Santa Rosa reservoir and outflows will be increased by a similar amount. Note that inflow net depletions are all zero; this is because all of the alternatives and the pre-1991 baseline have equal inflows.

Table 7. Net Depletion Mass Balance for Sumner Reservoir

Alternative	60-year average (acre-feet per year)			
	Net Depletion to Inflow	Net Depletion to Outflow	Net Depletion to Evaporation	Net Depletion to Change in Storage
Acme Constant	-68	-1494	1742	-317
Acme Variable	-26	-1204	1495	-317
Critical Habitat	211	276	253	-317
Taiban Constant	262	208	372	-317
Taiban Variable LRS	232	150	400	-317
Taiban Variable MRS	147	-166	629	-317
Taiban Variable HRS	62	-266	646	-317
No Action	347	-7	531	-177

Table 7 indicates Sumner reservoir operations were somewhat different between alternatives. The largest bypass alternatives saved a significant amount per year on evaporation, and released a similar amount as outflow. The higher ranges of Taiban Variable showed a similar trend with an order of magnitude less in terms of increased outflow from the reservoir. The lower range target alternatives and the lower end of the Taiban Variable Alternative all showed decreases in Sumner outflow. All of the modeled alternatives indicated saved evaporation at Sumner Reservoir; however, Acme Constant and Acme Variable showed the most.

Table 8. Net Depletion Mass Balance for Brantley Reservoir

Alternative	60-year average (acre-feet per year)				
	Net Depletion to Inflow	Net Depletion to Outflow	Net Depletion to Evaporation	Net Depletion to Change in Storage	Net Depletion to Change in Bank Storage
Acme Constant	3082	3075	-295	241	61
Acme Variable	2230	2349	-410	233	58
Critical Habitat	1188	795	147	199	47
Taiban Constant	1016	681	120	174	40
Taiban Variable LRS	1180	957	6	176	40
Taiban Variable MRS	1611	1347	24	195	46
Taiban Variable HRS	2260	2037	-28	203	48
No Action	2156	1642	380	110	23

Table 8 demonstrates that Brantley reservoir showed significantly reduced inflows and outflows under all the alternatives; ranging from 700 acre-feet per year to 3,100 acre-feet per year. Reservoir evaporation increased slightly for the higher bypass alternatives such as Acme Constant and Acme Variable. Most other alternatives showed slight increases to slight decreases with the No Action being the most significant in terms of evaporation savings.

Table 9. Net Depletion Mass Balance for Avalon Reservoir

Alternative	60-year average (acre-feet per year)					
	Net Depletion to Inflow	Net Depletion to Outflow	Net Depletion to Evaporation	Net Depletion to Change in Storage	Net Depletion to Seepage	Net Depletion to Diversion
Acme Constant	2963	-916	-12	0	-80	3971
Acme Variable	2292	-723	-10	0	-68	3094
Critical Habitat	732	-577	-4	0	-18	1331
Taiban Constant	621	-661	-4	0	-18	1304
Taiban Variable LRS	892	-400	-4	0	-18	1312
Taiban Variable MRS	1271	-323	-5	0	-29	1629
Taiban Variable HRS	1950	209	-6	0	-42	1789
No Action	1617	13	-5	0	-36	1645

Table 9 shows decreased inflows to Avalon Reservoir due to the alternatives, which subsequently reduced diversions to CID farms. Also contributing to reduced diversions are increased losses of project water supply to a greater frequency of conservation spills from Avalon (net depletions to outflows).

Table 10. Additional Reach Transmission Losses due to Alternative Reoperations

Alternative	60-year Average Additional Transmission Losses as Effective Brantley Storage (acre-feet per year)			
	Reach from Santa Rosa Reservoir to Sumner Reservoir	Reach from Sumner Reservoir to Brantley Reservoir	Reach from Brantley Reservoir to Avalon Reservoir	Total for All Reaches
Acme Constant	288	4202	-112	4378
Acme Variable	175	3133	-57	3251
Critical Habitat	156	981	-63	1074
Taiban Constant	186	860	-60	986
Taiban Variable LRS	181	1067	-66	1183
Taiban Variable MRS	152	1735	-75	1811
Taiban Variable HRS	136	2460	-87	2509
No Action wo/6-wk	111	2161	-25	2248

Table 10 demonstrates that all of the modeled alternatives indicate larger reach losses from Santa Rosa Reservoir to Sumner Reservoir and from Sumner Reservoir to Brantley Reservoir with the most significant of those occurring in the latter reach. Modeled transmission losses between Brantley Reservoir and Avalon Reservoir were slightly lower. From Santa Rosa to Sumner, increased losses are due to short spikes to move water down to Sumner for bypassing. Since Santa Rosa doesn't have a low-flow outlet works, water must be moved in short duration (1 to 3 days)-large blocks (typically 600 cfs). From Sumner to Brantley, increased losses are due to bypasses and shortened block releases with the former being the more significant cause for these increased losses. Decreased losses from Brantley to Avalon are mostly due to less water movement between these two reservoirs (since it was depleted upstream).

Table 11. Saved Reservoir Evaporation due to Alternative Reoperations

Alternative	60-year Average Saved Reservoir Evaporation (acre-feet per year)				
	Santa Rosa Reservoir	Sumner Reservoir	Brantley Reservoir	Avalon Reservoir	Total for All Reservoirs
Acme Constant	402	1132	-295	-12	1401
Acme Variable	257	972	-410	-10	958
Critical Habitat	60	164	147	-4	393
Taiban Constant	52	241	120	-4	447
Taiban Variable LRS	69	260	6	-4	371
Taiban Variable MRS	104	409	24	-5	595
Taiban Variable HRS	151	420	-28	-6	601
No Action	-86	345	380	-5	687

Table 11 shows that most saved evaporation occurs at Santa Rosa and Sumner reservoirs. This is from decreased detention time of water since bypassing occurs in Sumner Reservoir and also since Santa Rosa Reservoir frequently sends two day spikes out of the reservoir to accommodate bypasses through Sumner. Increased evaporation in Brantley is only noted for the higher target alternatives. This is due to the increased detention time of the bypass water that actually reaches Brantley.

The corrected reoperation net depletion includes all of the sources that water is lost or gained from in the Carlsbad Project due to reoperation. Table 12 shows that high-target alternatives such as Acme Constant and Acme Variable deplete more total water from the Project than the lower-target alternatives. Note that the second column in Table 12, which represents the dominant Project net depletion components, plus the third column in the table, which are insignificant components of the Project net depletions, equals the fourth column in the table.

In Table 13, the reoperation net depletions indicate all the effects of reoperations with the effects of Project net depletions due to differences in spills removed. The sum of the Project net depletion components shown in the second and third columns equals the total reoperation net depletion shown in the fourth column.

Table 12. Corrected Reoperation Net Depletions to CID

Alternative	60-year average (acre-feet per year as Effective Brantley Storage)		
	Additional Transmission Losses, plus Water Lost to Spills, minus Saved Evaporation	Net Depletions from Seepage and Brantley Bank Storage	Corrected Reoperation Net Depletion
Acme Constant	3892	19	3911
Acme Variable	3017	10	3027
Critical Habitat	1258	-28	1230
Taiban Constant	1200	-22	1178
Taiban Variable LRS	1212	-23	1189
Taiban Variable MRS	1540	-17	1523
Taiban Variable HRS	1698	-6	1692
No Action wo/6-wk	1547	13	1560

Table 13. Reoperation Net Depletions to CID

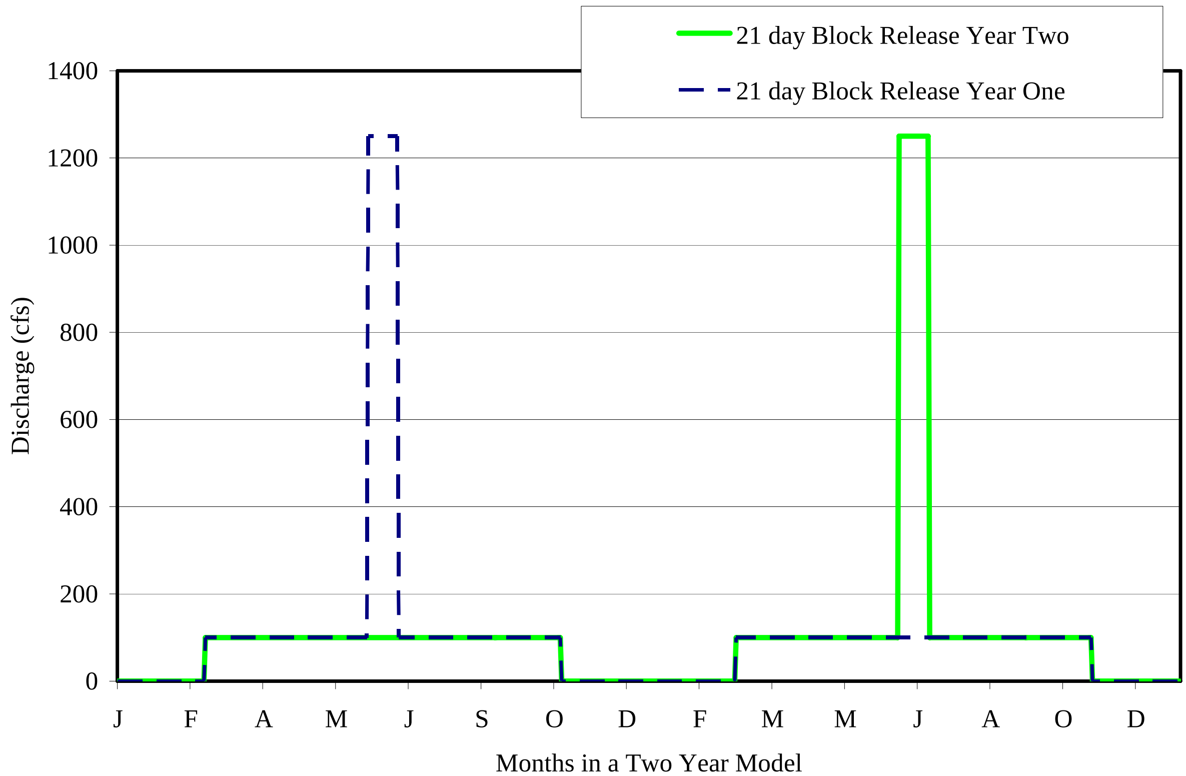
Alternative	60-year average (acre-feet per year as Effective Brantley Storage)		
	Additional Transmission Losses minus Saved Evaporation	Net Depletions from Seepage and Brantley Bank Storage	Reoperation Net Depletion
Acme Constant	2976	19	2995
Acme Variable	2293	10	2304
Critical Habitat	681	-28	653
Taiban Constant	539	-22	517
Taiban Variable LRS	812	-23	789
Taiban Variable MRS	1217	-17	1200
Taiban Variable HRS	1908	-6	1901
No Action wo/6-wk	1560	13	1573

Erroneous Net Depletions

Net depletion numbers must be used with caution. Over a 60-year model period, it is the average result that is more meaningful than discrete values from year-to-year. This is because year-to-year variables in operations can cause net depletions in that year that are canceled out in some other year by the same variable. This variable difference is caused by the different timing of operations between two model simulations. Consider spills from Avalon dam. One model may spill in the modeled year 1941 while the other spills an equal amount in 1942. In one year the interpretation using annual net depletions will show a large net depletion to spills, but by the next year this net depletion will be canceled out since the other model also spilled. This is also a problem with spills from Sumner dam and the subsequent reduced efficiency that a *flood bypass* causes. Ultimately, this causes problems when trying to identify annual depletions due to bypassing for the shiner as opposed to bypassing for flood control. These types of erroneous net depletions (erroneous because they have nothing to do with the reoperations) are caused by variations in operational aspects of the models; other problems also arise from the normalization of reservoir storage in the equations.

Evaluating net depletions on an annual basis also leads to problems using Effective Brantley Storage. Consider the two modeled block releases over a two-year period depicted in Figure 18. One model releases a block release in the first year and the other doesn't. The second year, the model that didn't make a block release does, and the other doesn't. It is apparent that operations in one model are a "mirror" of the other. Note that this particular modeled block release (21 days at 1,150 cfs) is 80% efficient. That is 80% of the modeled release volume reached Brantley Reservoir as modeled inflow. At the end of the first year, storage counted in Brantley for the model that made a block release would be 80% of the release volume (0.80*47,900 acre-feet) or 38,300 acre-feet, the model that didn't make one still only receives 75% credit for the same volume still stored in Sumner as Effective Brantley Storage (0.75*47,900 acre-feet), which is 35,900 acre-feet. After the first year, an erroneous net depletion of 2,400 acre-feet will be calculated using Effective Brantley Storage. After the second year, when both releases have made it to Brantley, both are counted with 80% efficiency and the erroneous net depletion indicated the first year is gone.

Figure 18. 21-Day "Mirror" Block Releases Over a Two Year Period

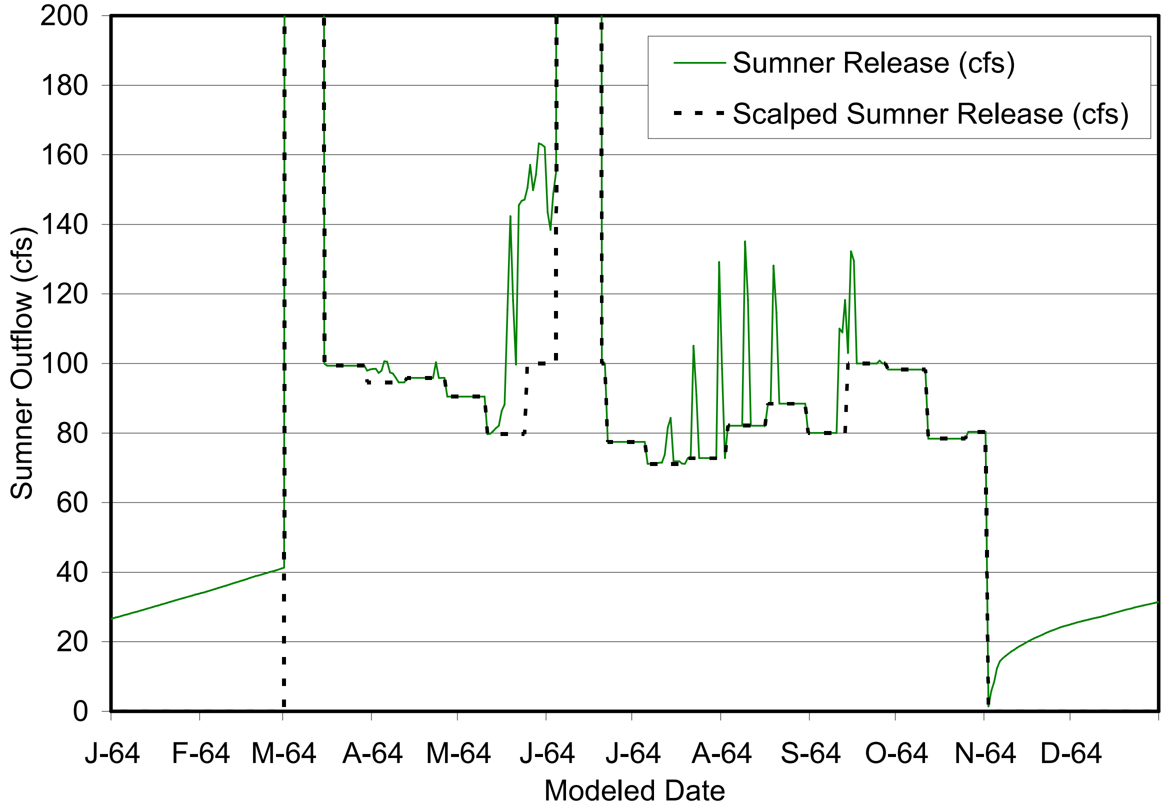


Calculation of Additional Transmission Losses in the Reach from Sumner to Brantley due to Bypass Operations Only

Due to the problems calculating the annual year-to-year variability of net depletions to the Project due to reoperations, a different approach was taken to isolate the annual transmission losses due to bypasses for the shiner. This was deemed the only acceptable way to estimate the variability without including other aspects of operations that could influence the results. Since bypasses for the shiner are the dominating loss in net depletions to the Project, annual maximums due to bypassing are a conservative estimate of maximum net depletions since they won't include the subsequent saved evaporation or increased losses in conservation spills that a bypass would create (Tetra Tech, 2003e).

In order to estimate transmission losses due to bypasses for the shiner, modeled inflows to Brantley without the shiner bypasses were determined. Bypasses were removed from Sumner outflows (See Figure 19) and this release was modeled to Brantley reservoir to determine the corresponding inflow volume. This inflow was then compared with the original Brantley inflow to determine annual efficiencies for the annual bypass volumes. These efficiencies were then subtracted from an average modeled efficiency for an appended block release volume (82%--which assumes an average bypass volume appended to a block release at a typical block discharge) to determine the additional transmission depletion due to the bypass (as opposed to moving the water by block release).

Figure 19. Example of Sumner Outflow Including Bypass for Shiner and Sumner Outflow with Bypass Removed (Scalped)



Results for Additional Transmission Losses in the Reach from Sumner to Brantley due to Bypass Operations Only

Maximum additional transmission depletions in the reach between Sumner Reservoir and Brantley Reservoir, due to bypassing only, are shown in Table 14. It is apparent that the maximum additional transmission depletions follow the same flow target-net depletion trend: larger flow targets cause larger maximum additional transmission depletions among alternatives. Minimum additional transmission depletions in the same reach due to only bypassing are shown in Table 15. These values also exhibit the same trend with bypass flow targets among alternatives.

Table 14. Average and Maximum Additional Transmission Depletions for the reach between Sumner Reservoir and Brantley Reservoir-Shown with Modeled Maximum Depletion years, Bypass Volumes, and Efficiencies

Alternative	Average 60-Year Transmission Depletion (AF) [1]	Maximum Occurs in Modeled Year	Bypass Volume Leaving Sumner (AF)	Bypass Volume Arriving at Brantley (AF) [2]	Bypass Efficiency	Estimated Maximum Additional Transmission Depletion (AF) [3]
Acme Constant	4202	1979	19086	8845	46%	**6900**
Acme Variable	3133	1943	13631	5314	39%	**5900**
Critical Habitat	981	1961	3001	1103	37%	**1400**
Taiban Constant	860	1971	3995	1548	39%	**1700**
Taiban Variable-LRS	1067	1971	4303	1623	38%	**1900**
Taiban Variable-MRS	1735	1975	5012	1523	30%	**2600**
Taiban Variable-HRS	2460	1943	6208	1411	23%	**3700**
No Action	2161	1943	11399	3954	35%	**5400**

[1] Using 60-year NEPA simulation, average outflow net depletion at Sumner multiplied by 75% efficiency, and average inflow net depletion at Brantley **(Sumner to Brantley reach only)**.

[2] Using identical (pattern) Sumner outflow hydrograph with all bypass removed to determine Brantley Inflow scalping hydrograph.

[3] Assumes 82% efficiency for appended block release volumes -- estimated transmission depletion **for reach between Sumner and Brantley Reservoirs for bypass operations only**

Table 15. Average and Minimum Additional Transmission Depletions for the reach between Sumner Reservoir and Brantley Reservoir-Shown with Modeled Maximum Depletion years, Bypass Volumes, and Efficiencies

Alternative	Average 60-Year Transmission Depletion (AF) [1]	Minimum Occurs in Modeled Year	Bypass Volume Leaving Sumner	Bypass Volume Arriving at Brantley (AF)[2]	Bypass Efficiency	Estimated Minimum Additional Transmission Depletion (AF) [3]
Acme Constant	4202	1958	4305	1809	42%	**1700**
Acme Variable	3133	1946	7027	3789	54%	**2000**
Critical Habitat	981	1959	243	4	2%	**200**
Taiban Constant	860	1986	15	2	15%	**10**
Taiban Variable-LRS	1067	1986	36	3	7%	**30**
Taiban Variable-MRS	1735	1958	706	252	36%	**320**
Taiban Variable-HRS	2460	1958	1826	603	33%	**900**
No Action wo/6wk	2161	1991	3928	2961	75%	**270**

[1] Using 60-year NEPA simulation, average outflow net depletion at Sumner multiplied by 75% efficiency, and average inflow net depletion at Brantley **(Sumner to Brantley reach only)**.

[2] Using identical (pattern) Sumner outflow hydrograph with all bypass removed to determine Brantley Inflow scalping hydrograph.

[3] Assumes 82% efficiency for appended block release volumes -- estimated transmission depletion **for reach between Sumner and Brantley Reservoirs for bypass operations only**

3.4 Net Depletions to State-line Flows

Net depletions to State-line flows are calculated using the same action to baseline comparison as net depletions to the Carlsbad Project. Modeled alternative flows at the State line, over a specified time period, are subtracted from modeled pre-1991 baseline flows, over the same time period, at the State line. Since State-line flow is only one net depletion parameter, it greatly simplifies the computations; however, State-line flows are still affected by modeled differences in conservation spills from the Carlsbad Project.

Calculation of Net Depletions to State-line Flows

To remove the annual effect of conservation spills from modeled State-line flows, a similar approach to Equation 3.3 was used. The annual differences in spills were removed from the annual State-line net depletions and the annual long-term average of those spills was added back into all of the annual State-line net depletions. Equation 3.12 is the formula for removing these spill differences.

$$\begin{matrix} \textit{Annual Corrected} \\ \textit{Net Depletion to} \\ \textit{State - line Flows} \end{matrix} = \begin{matrix} \textit{Annual Net} \\ \textit{Depletion to} \\ \textit{State - line Flows} \end{matrix} - \begin{matrix} \textit{Annual Net} \\ \textit{Depletion to} \\ \textit{Avalon Spills} \end{matrix} + \begin{matrix} \textit{60 - Year Average} \\ \textit{Net Depletion to} \\ \textit{Avalon Spills} \end{matrix} \qquad \text{Eq. 3.12}$$

Modeled Results for Net Depletions to State-line Flows

Figures 20-27 illustrate the year-to-year variability of net depletions to State-line flows. 60-year averages are also printed on each figure. Once again the same general net depletion trend is noted among alternatives with higher versus lower targets. Higher flow target alternatives, such as Acme Constant and Acme Variable, show larger net depletions to State-line flows and lower flow target alternatives, such as Taiban Constant and Critical Habitat, show smaller net depletions to State-line flows.

Figure 20. Net Depletions to State-line Flows for the No Action Alternative

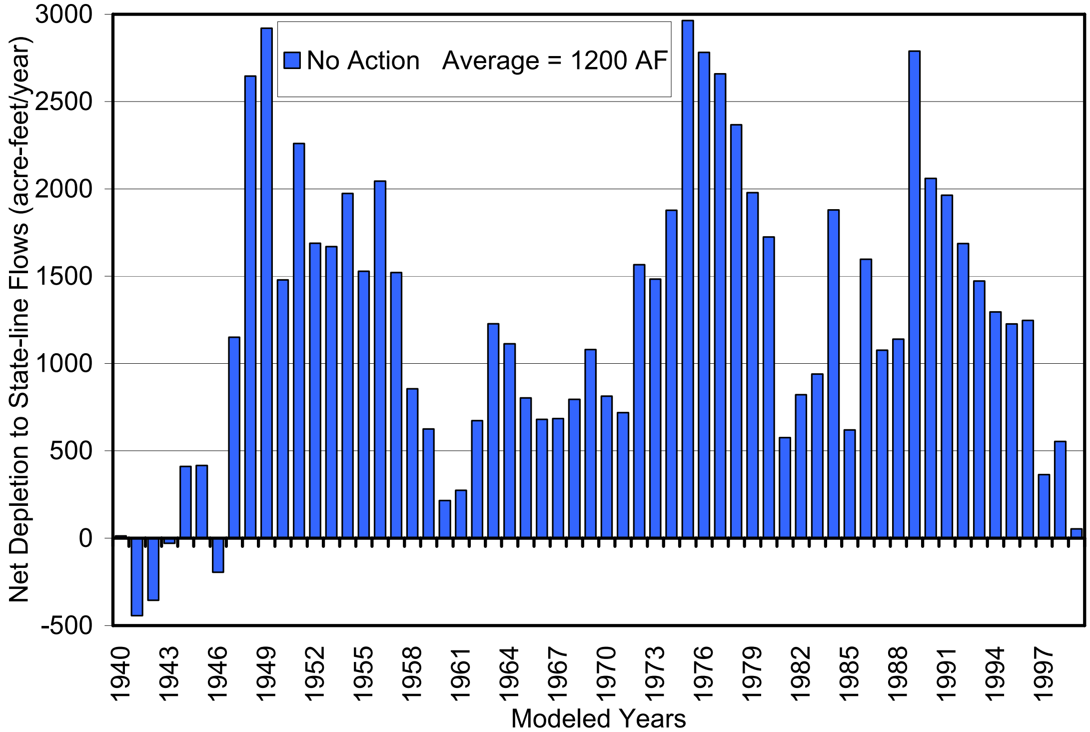


Figure 21. Net Depletions to State-line Flows for the Taiban Constant Alternative

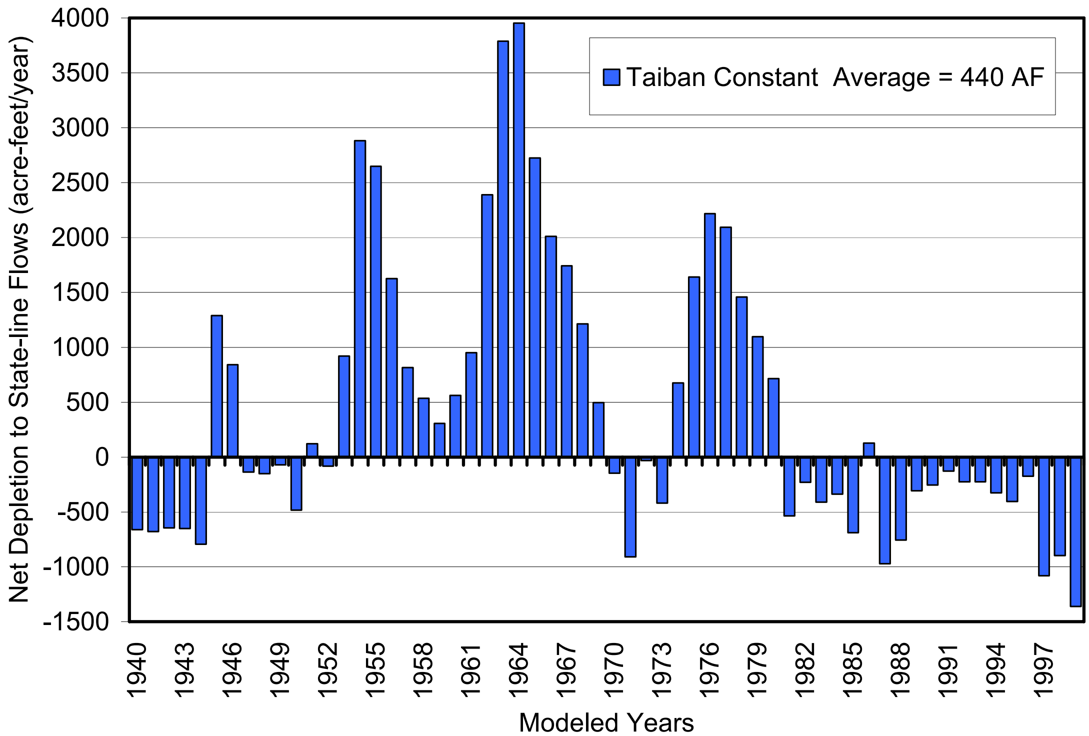


Figure 22. Net Depletions to State-line Flows for the Taiban Variable Alternative (High Range, 55 cfs, Irrigation Season Target)

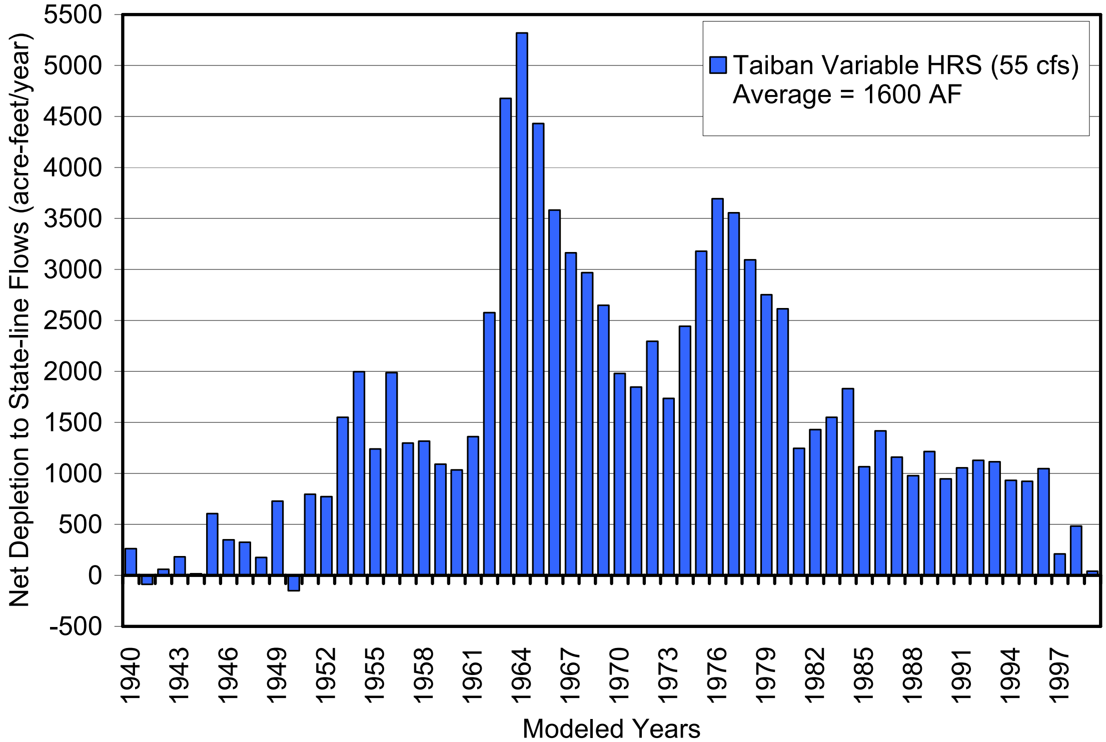


Figure 23. Net Depletions to State-line Flows for the Taiban Variable Alternative (Mid-Range, 45 cfs, Irrigation Season Target)

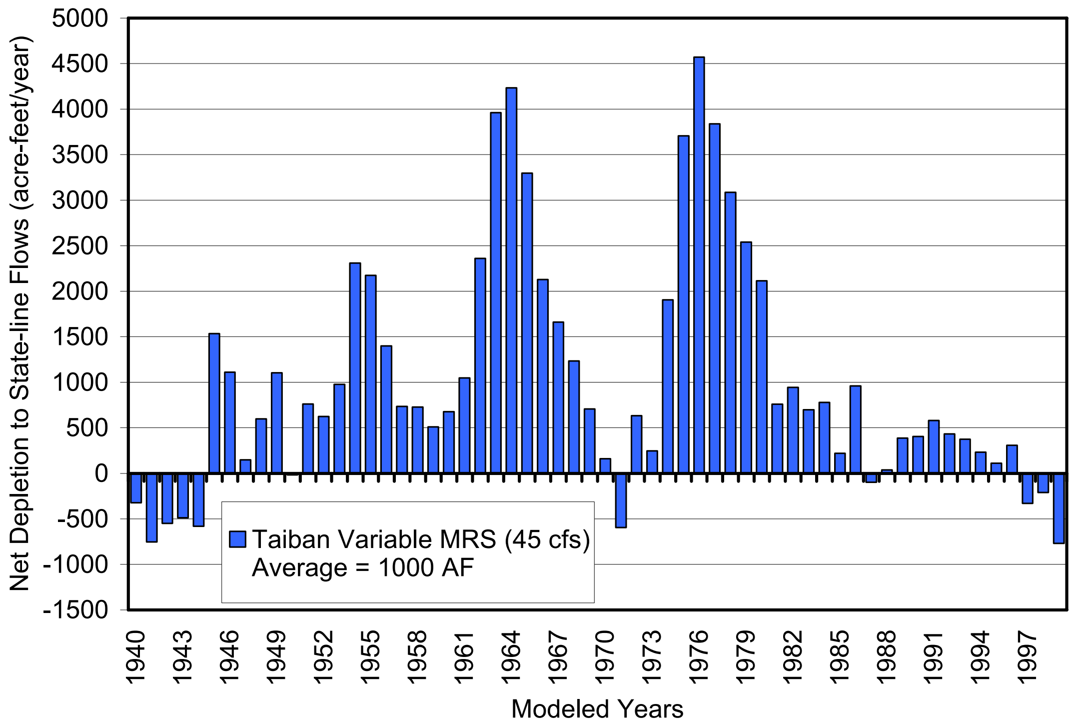


Figure 24. Net Depletions to State-line Flows for the Taiban Variable Alternative (Low Range, 40 cfs, Irrigation Season Target)

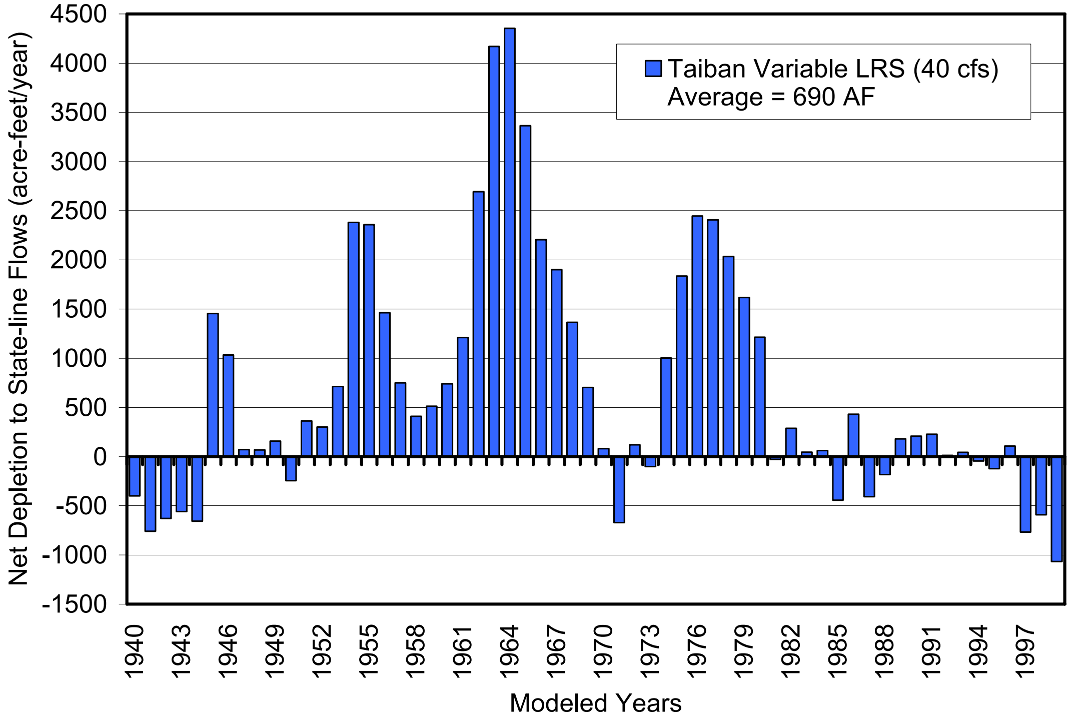


Figure 25. Net Depletions to State-line Flows for the Acme Constant Alternative

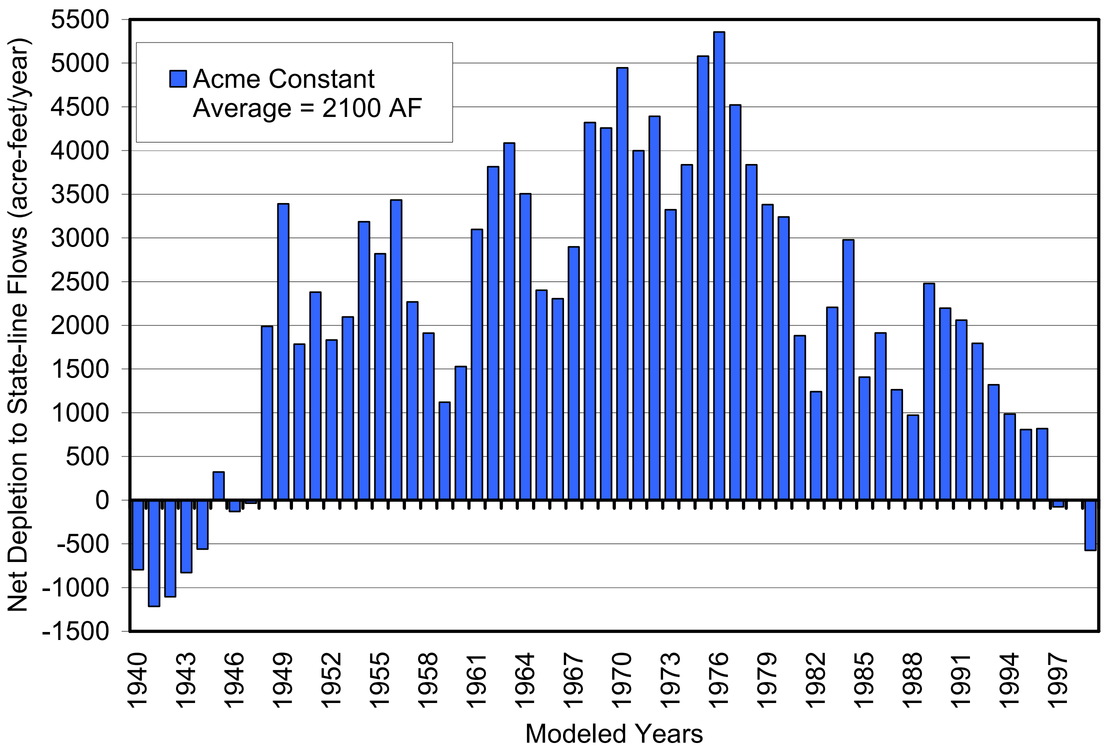


Figure 26. Net Depletions to State-line Flows for the Acme Variable Alternative

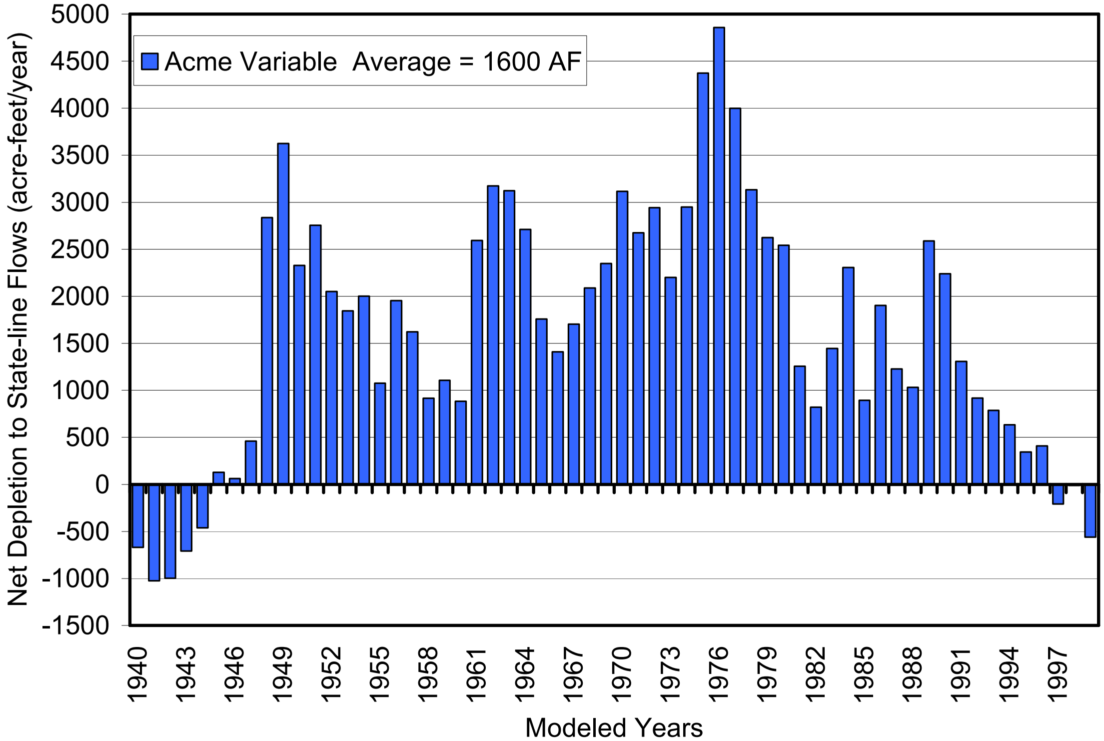
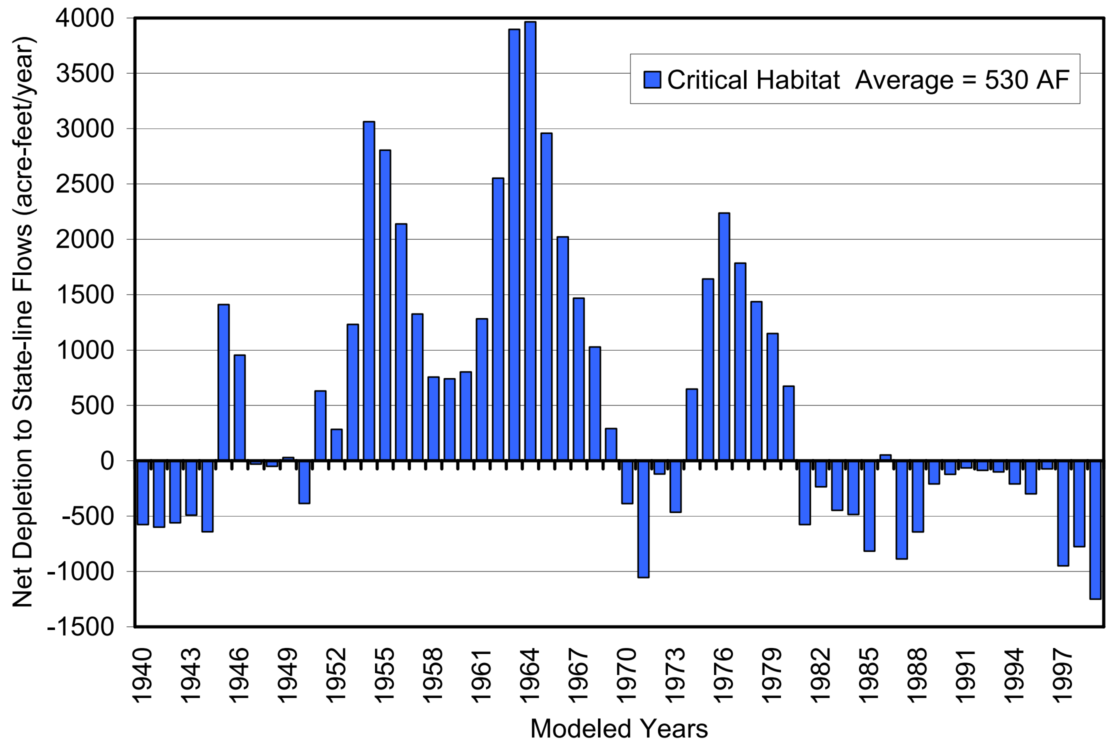


Figure 27. Net Depletions to State-line Flows for the Critical Habitat Alternative



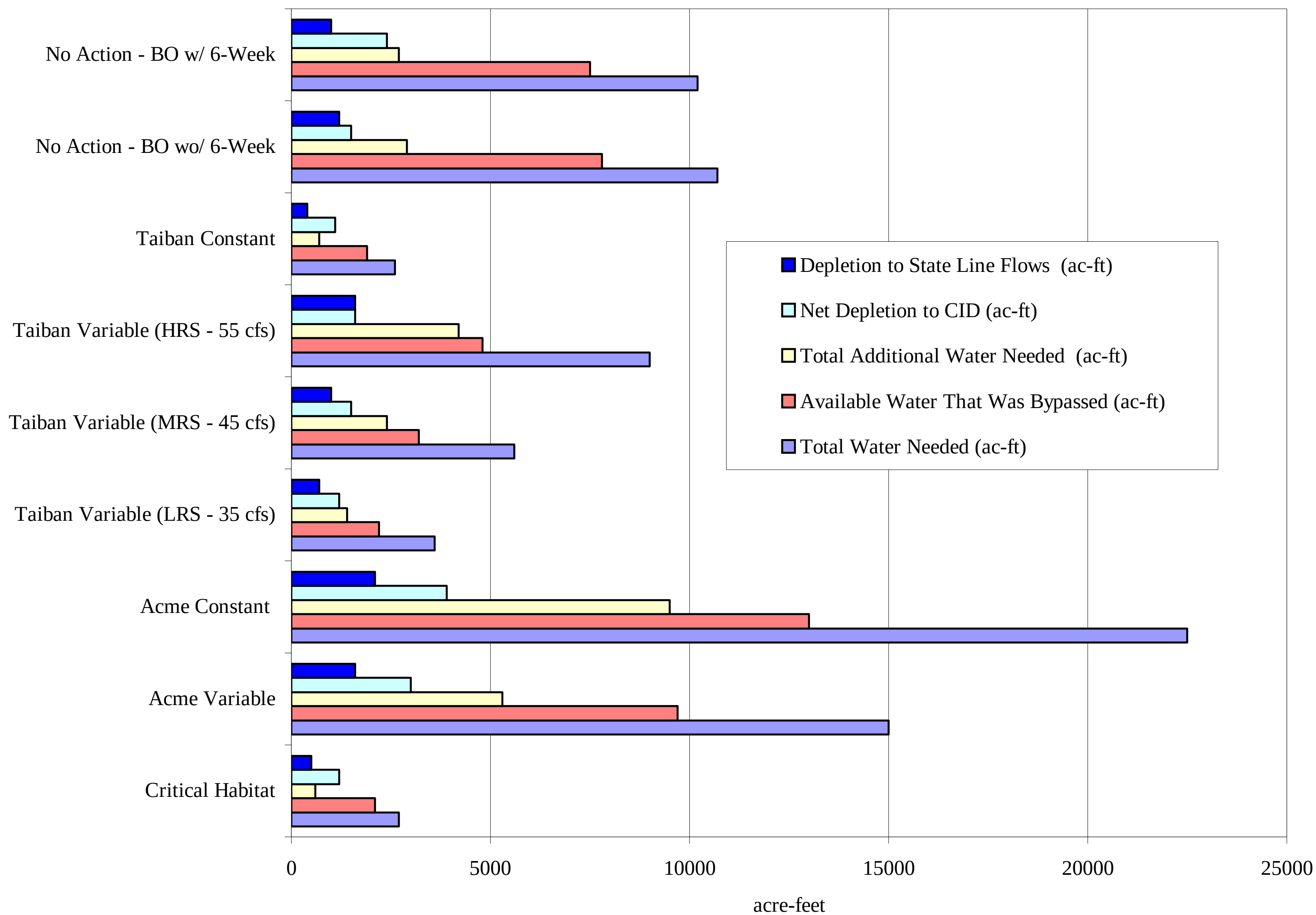
3.5 Summary of Alternative Water Accounting and Net Depletions

Table 16 is a summary of the water accounting results for all of the alternatives. The table summarizes the total water needed for each alternative to meet the target flows as much as possible, the available water that was bypassed, and the additional amount of water that would be needed to meet the demand (the difference between the first two columns). The table also summarizes the corrected reoperation net depletion to CID and the net depletion to State-line flows. The values in the last two columns are the 60-year average values for each alternative. Figure 28 is a graphical representation of the numbers contained in Table 16.

Table 16. Alternative Summary Water Accounting Table

Alternative	Total Water Needed (ac-ft)	Available Water that was Bypassed (ac-ft)	Additional Water Needed (AWN) to Meet Demand Completely (ac-ft)	Corrected Reoperation Net Depletion to CID (ac-ft)	Net Depletion to State Line Flows (ac-ft)
No Action	10,700	7,800	2,900	1,500	1,200
Taiban Constant	2,600	1,900	720	1,100	440
Taiban Variable (HRS - 55 cfs)	9,000	4,800	4,200	1,700	1,600
Taiban Variable (MRS - 45 cfs)	5,600	3,200	2,400	1,500	1,000
Taiban Variable (LRS - 40 cfs)	3,600	2,200	1,400	1,200	690
Acme Constant	22,500	13,000	9,500	3,900	2,100
Acme Variable	15,000	9,700	5,300	3,000	1,600
Critical Habitat	2,700	2,100	620	1,200	530

Figure 28. Modeled 60-Year Annual Averages of PBNS Alternative Total Water Needs, Bypasses, Additional Water Needs.



The first column in Table 16, “total water needed”, represents the amount of water that is required to be released from Sumner Dam to meet the specified flow criteria for each alternative. The “available water that was bypassed” (column 2) represents the amount of water that was bypassed. In some cases there is more inflow than is needed to meet the targets and this surplus remains in Sumner Reservoir for CID. The bypass flows do not include any additional water such as water taken from CID storage, water supplied through options determined by the water offset options group (WOOG), or additional water acquisition (AWA) options, or water from a fish conservation pool (FCP). Column 3, “additional water needed” or AWN represents the difference between column 1 and column 2. It should be noted that AWN is what is required to meet all the targets, all of the time. If a fish conservation pool is used for this purpose, this is the amount of water that would be needed for the pool, without considering evaporation. It is not necessarily the volume of the pool that would be needed if the pool is stipulated to be a refillable pool.

Alternative Comparisons – Water Accounting and Net Depletions

Water that travels from Sumner Reservoir to Brantley Reservoir incurs losses such as evaporation and transpiration. When water is moved from one reservoir to another in large amounts, i.e. higher discharges for consecutive days, the losses incurred are less than if the water is transferred at lower discharges over longer periods of time. The season also affects the rate of loss as more water is lost during the hotter, dryer periods such as summer than is lost during cooler times of the year. All of the alternatives alter the flow duration pattern, decreasing the amount and frequency of block releases and increasing the volume of water that is transported at lower flows. This alteration of the hydrograph causes an increase in transmission losses between the two reservoirs. The fourth column of Table 16 represents the net depletion to CID supply mostly due to these losses.

Although the 60-year average masks the year-to-year variability of the accounting numbers, the averages are good for comparing the water use of the different alternatives with each other. With regard to water use, the following qualitative statements can be made concerning the alternatives:

- The Acme Alternatives require the most total water and additional water. Total water is what would be needed to meet the criteria set forth in the alternative and additional water is water that would be need to meet targets 100% of the time in addition to CID bypass water. Due to the large amount of water bypassed for these alternatives, the impacts to CID and flows at the state line are significant.
- The Taiban Variable Alternative uses a minor to moderate amount of water as far as total water needs and bypasses are concerned.
- Results for alternatives with low additional water needs indicate these alternatives have more reasonable flow targets with respect to incoming supply. Conversely, note that the Taiban Variable-High Range Summer target (55 cfs) sub-alternative actually requires more additional water than both permutations of the No Action Alternative. For the high range summer sub-alternative, it is evident that targets may be set unreasonably high at times when there is not much CID supply available to bypass through Sumner Reservoir.
- The Critical Habitat and Taiban Constant Alternatives use the least amount of total water and require a negligible amount of additional water when compared to the Acme Alternatives.
- Net Depletions to flows at the New Mexico—Texas State line correlate directly with the total water needs of the alternatives including the No Action Alternative.

4.0 Summary and Conclusions

Preliminary alternative modeling for the current NEPA process to reoperate Sumner Dam showed varied results among the alternatives. Total water needs for alternatives ranged from fairly minor (2,600 acre-ft/year for Taiban Constant) to extremely major amounts (22,500 acre-ft/year for Acme Constant).

Improvements in flow duration due to reoperations are evident; but since incoming supply is limited, no single alternative using bypasses alone prevents intermittency at the Acme node. The flow exceedance improvements are mostly due to availability of incoming supply to hit targets during the winter. In the summer, these supplies are sporadic and will cause intermittency at times unless sufficient additional water acquisition (AWA) is acquired to meet the target demands (AWN) of the alternatives. The Critical Habitat and No Action Alternatives will always have some intermittency since they were designed that way.

Modeling results indicate that net depletions to both Carlsbad Project supply and the State-line are caused by bypassing, and larger flow target alternatives cause larger net depletions to 60-year averages and 60-year maximums. 60-year average values are useful for determining trends for components of net depletions such as average additional transmission losses, average saved evaporation, or average decreases in conservation spills, but annual values should be used with caution (in the case of State-line flows) or not at all (for Carlsbad Project supply).

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Technical Appendix to the:

Carlsbad Project Water Operations and Water Supply Conservation Environmental Impact Statement

Pecos River Bypass and Additional Water Needed (AWN) Modeling and Post-Processing

January 2006

By Hydrosphere Resource Consultants, Inc.

HYDROSPHERE
Resource Consultants

TABLE OF CONTENTS

1.0 Introduction

To evaluate the impacts of NEPA alternatives to reoperate Sumner Dam for the Pecos Bluntnose Shiner (PBNS), the Hydrology/Water Operations Work Group (HWG) modeled alternatives using the Pecos River Decision Support System (PRDSS) (Barroll et al, 2004; Hydrosphere Resource Consultants, 2003 and 2005; and Tetra Tech, Inc, 2003a and 2003b). The PRDSS consists of a RiverWare surface water model, two MODFLOW groundwater models, and an MS Access-based output post-processor/data reformatter. Model outputs were saved in an MS Access results database and results for requested resource indicators were distributed to EIS work groups. This document details RiverWare modeling and post-processing calculations for bypass operations alone, and computation of additional water needed (beyond the bypasses) to meet flow targets for the PBNS 100% of the time.

2.0 Summary of Alternatives Modeling and Initial Post-Processing

The following describes alternatives bypass modeling and the RiverWare "fish rules" used to simulate bypass operations, as well as the post-processing of model results to determine the additional water needed (AWN) in excess of bypasses to meet fish flow targets. Model runs including both bypasses and AWN water are also described.

2.1 Bypass-Only Modeling

Individual RiverWare surface water models (run on a daily timestep) and rulesets were created for each alternative. Alternatives, designed to conserve the PBNS, vary mostly by flow targets[1] in the PBNS Upper Critical Habitat and at the Taiban and Acme gages (a matrix summarizing alternatives is presented in attachment A).

In RiverWare, a series of rules, collectively referred to as the "fish rules", were designed to model water bypassed through Sumner reservoir (Sumner) to meet NEPA alternative flow targets for the PBNS. Flow targets may vary according to the irrigation season[2] and the hydrologic condition (wet, dry, and average). The fish rules determine local inflows above Sumner which are "available[3]", i.e., in excess of the Fort Sumner Irrigation District's (FSID) entitlement, to be bypassed to meet flow targets. In these model simulations, water was not taken from Carlsbad Irrigation District (CID) storage to meet flow targets. The Bureau of Reclamation (Reclamation) and CID jointly hold the right to divert and store river water for the benefit of the Carlsbad Project. Bypasses to meet flow targets occur when Reclamation does not exercise its right to divert and store for the Carlsbad Project, with the understanding on CID's part that Reclamation will offset depletions to CID's supply associated with that bypass.

[1] The Taiban Constant and Taiban Variable alternatives specify flows at the Taiban gage. The Acme Constant and Acme Variable alternatives specify flows at the Acme gage. The Critical Habitat alternative specifies flows at the both the Taiban and Acme gages as well as flows to keep the river wet from Taiban to the mouth of Crockett Draw (located at the lower end of the upper Critical Habitat.) The No Action alternative specifies flows at Acme and to the mouth of Crocket Draw.
[2] The irrigation season extends from March 1 through October 31 and this time period is often referred to as "summer." The non-irrigation season extends from November 1 to the end of February and is often referred to as "winter."
[3] Available local inflows which are storable, i.e., in excess of FSID's diversion request, become part of Carlsbad Irrigation District (CID) supply.

2.2 Fish Rule Overview

One basic premise behind the fish rules is that the Pecos River experiences characteristic losses that vary by season over the course of the year. These average daily losses have been determined from historical gage data and are dependent on the magnitude of the flows. Figure 1 illustrates how loss coefficients vary both seasonally and according to the flow. The larger a coefficient, the greater the loss. Losses are lowest in the winter months, ramp up in the spring, are highest in the summer, and ramp down in the fall. In addition, loss coefficients decrease as flows in the river increase, i.e. for higher flows a smaller percentage of the total flow is lost. To meet a flow target at a particular gage below Sumner dam, sufficient water must be passed through Sumner dam to overcome the expected losses.

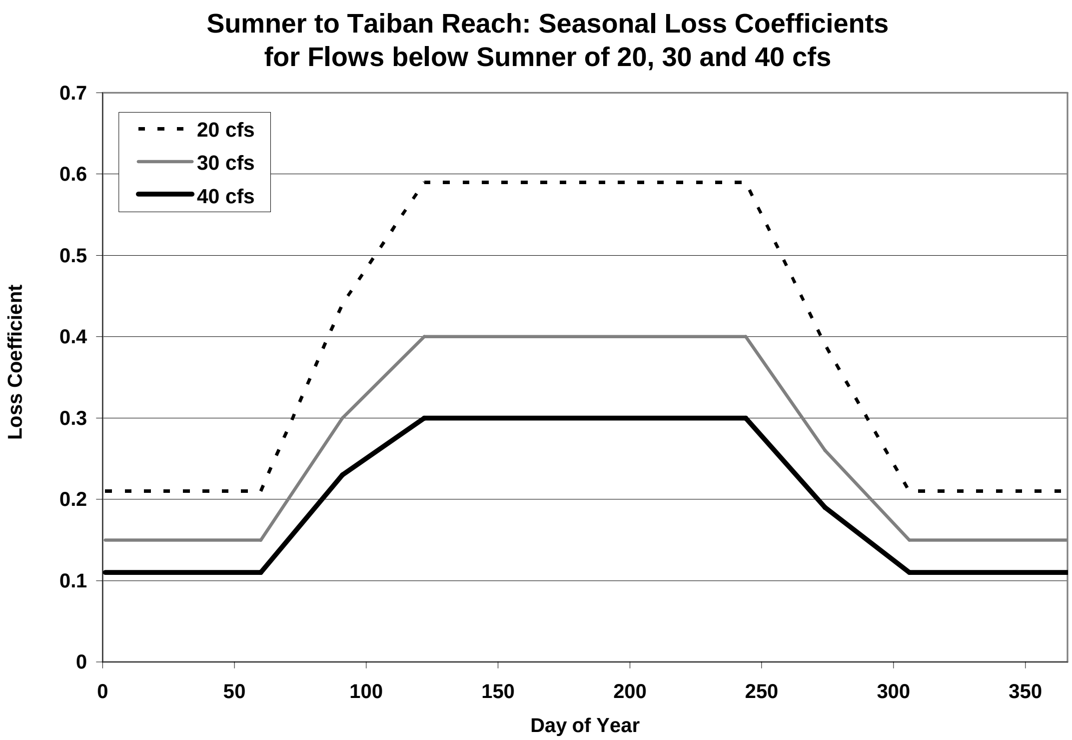

Figure 1: Seasonal Loss coefficients applied to flows of 20, 30 and 40 cubic feet per second (cfs) below Sumner Dam.

In the RiverWare model, one of the fish rules first converts all target flows (regardless of target location) to a flow needed at Taiban. If an alternative specifies a flow target at a location other than Taiban, the flow target is converted to a Taiban flow via the loss function between the subject gage and the Taiban gage. Flows needed at Taiban are then converted to flows at the Pecos River below Sumner Dam using the loss function illustrated in Figure 1 and by subtracting off flows already in the river at Taiban (i.e. FSID return flows and non-applied water). Again, following the basic premise described above, enough water must be released from Sumner to cover river losses in the Sumner to Taiban reach. RiverWare does not easily solve for river losses until the inflows to the reach are known, so the previous day's loss for the Sumner to Taiban reach was used as an approximation. To determine the total water needed in the river below Sumner to meet both FSID and PBNS demands, FSID's diversion requests are added to the water needed for the fish. There are three different RiverWare functions used to determine the total water needed below Sumner depending on the flow target location (Figs 2 – 4). Note that the name of the function specifies the flow target location.

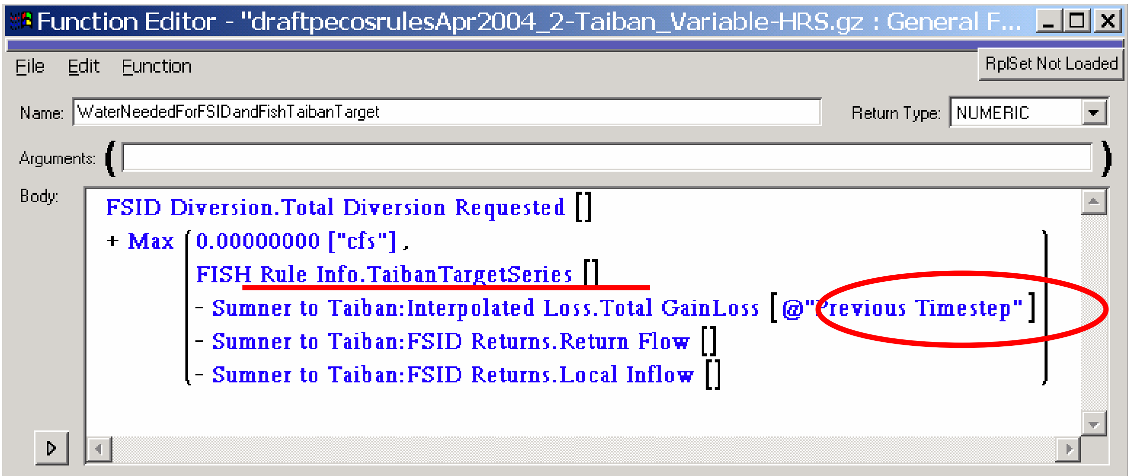

Figure 2: RiverWare ruleset function which sets the Sumner outflow needed to meet FSID's diversion request and the fish flow target for Alternatives with Taiban flow targets.

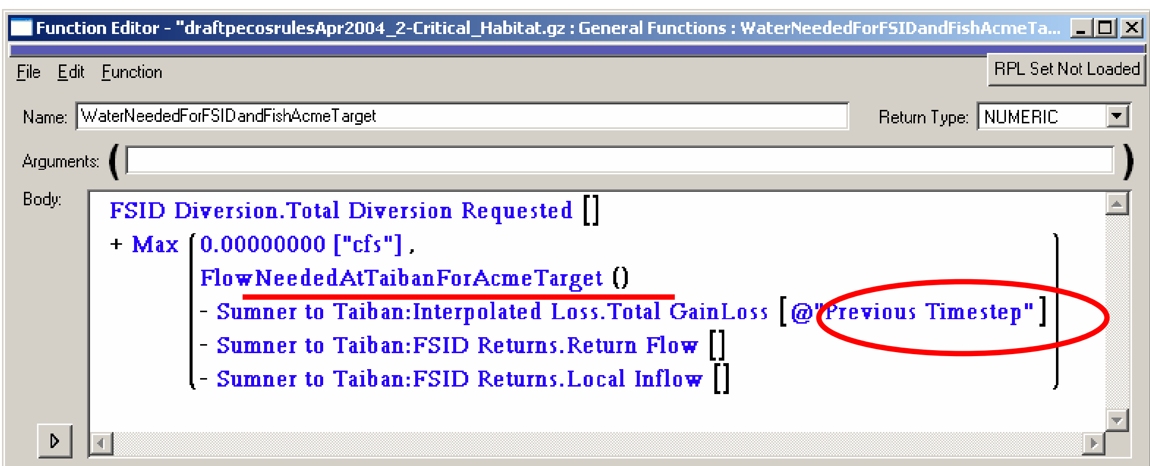

Figure 3: RiverWare ruleset function which sets the Sumner outflow needed to meet FSID's diversion request and the fish flow target for alternatives with Acme flow targets.

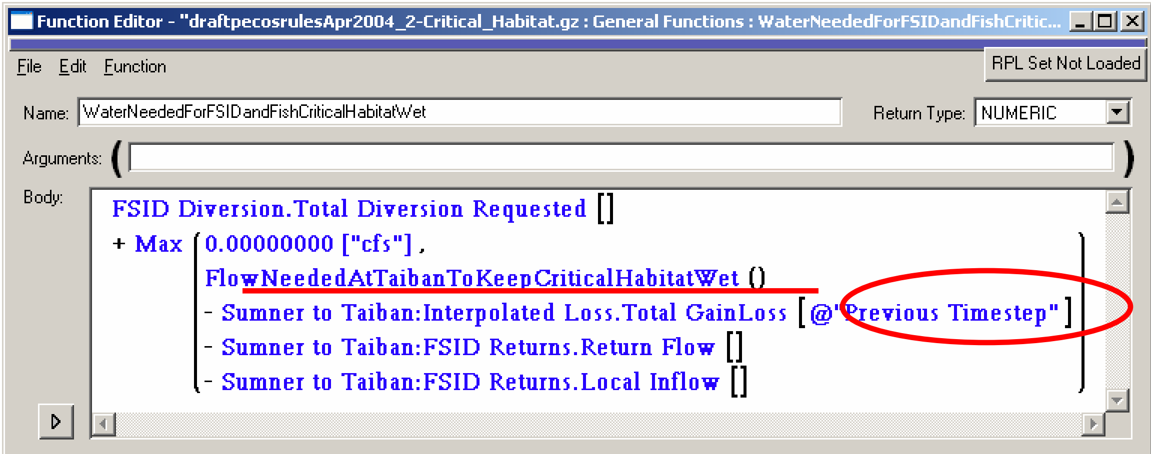

Figure 4: RiverWare ruleset function which sets the Sumner outflow needed to meet FSID's diversion request and the fish flow target for alternatives with Critical Habitat flow targets.

The Critical Habitat and No Action alternatives have Taiban and/or Acme targets as well as dry summer targets designed to keep the upper critical habitat wet. For these alternatives, one of the fish rules, “Acme TargetWaterNeededForFSIDandFish” rule (fig. 5), determines whether to call the “WaterNeededForFSIDandFishAcmeTarget” (fig. 3) or “WaterNeededForFSIDandFishCriticalHabitatWet” (Fig. 4) function when calculating the water needed below Sumner for FSID and the fish. During dry summer periods, the Acme target series is set to 0.0 cfs. The rule then evaluates the Acme target, and if it is set to 0.0, calls the “WaterNeededForFSIDandFishCriticalHabitatWet” function. Otherwise, the “WaterNeededForFSIDandFishAcmeTarget” function is called.

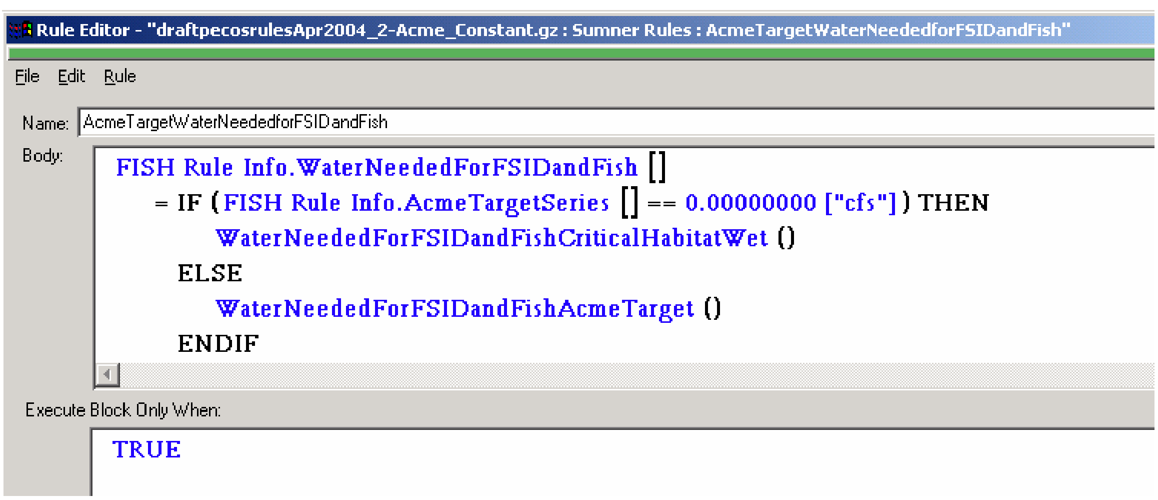

Figure 5: Fish Rule which sets the water needed below Sumner for FSID and the fish for alternatives with Critical Habitat and/or Acme targets.

Once the total water needed for FSID and the fish has been determined, additional RiverWare rules compare this value to Sumner inflows, bypassing what is available. FSID's diversion requests are fully met before water is bypassed for the fish.

2.3 Additional Water Needed Post-Processing and Modeling

The definition of each alternative implies having sufficient water to meet the targets 100% of the time. In modeling the NEPA alternatives, bypassing incoming available water was often insufficient to meet the flow targets for many of the alternatives at all times. To characterize those periods when available storable inflows were insufficient to meet flow targets via bypasses, additional amounts of water for each alternative that would be required to meet the targets 100% of the time were quantified by post-processing bypass-only model results. This additional water is referred to as AWN[4] (additional water needed). The acquisition and management of this water would likely include (but is not limited to) storage in a fish conservation pool (FCP) in either Sumner or Santa Rosa reservoir.

AWN to meet fish target flows in excess of bypasses was calculated by post-processing results from alternative model simulations. On a daily basis, bypasses were evaluated to determine if they were sufficient to meet fish target flows. If additional water was needed, this was considered AWN.

2.4 Fish Conservation Pool Model Runs

To evaluate the effects of a fish conservation pool on Pecos River flows to Acme, a simplified “mini” RiverWare model for the reach below Sumner down to Acme was created. The NEPA RiverWare ruleset was also condensed to contain only the FSID portion of the RiverWare rules. For each alternative, a set of Sumner outflows, including bypasses and FCP water was developed for input into the “mini” model. Except for Sumner outflows being input rather than being set by rules, the "mini" model is consistent with the complete model for the reaches modeled.

Several runs of the mini-model were initially done to evaluate the impacts of a finite FCP in Sumner Reservoir which was refilled on January 1 of each year. For each alternative, revised Sumner outflows were generated by taking daily Sumner outflows from the alternative simulations with bypass operations and adding water from the FCP pool in order to meet the flow target. In any given year, once the FCP ran out, Sumner outflows were set equal to the bypass operations values. Taiban, Dunlap and Acme flows were output from this simplified model and flow exceedance curves and intermittency statistics generated.

3.0 RiverWare Fish Rule Limitations

While examining results from bypass model runs, the fish rules were found to have several limitations. The total water needed for the fish was not adjusted in the rules for times when Sumner was spilling or there was a block release. Additional model data which had not been saved and exported was needed to evaluate the impact of flow targets on certain resource indicators. Also, the use of the previous day's loss in the Sumner to Taiban reach led to over- and under-estimations of the actual modeled loss.

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[4] The HWG first referred to AWN water as FCP water, though not all additional water needed (in additional to bypasses) would likely be maintained in a pool in Sumner Reservoir and/or Santa Rosa Reservoir. Additional Water Acquisition (AWA) terminology found throughout EIS documentation should not be confused with AWN. AWN is the total demand to meet flow targets 100% of the time after all available inflows above FSID’s diversion right have been bypassed. AWA is limited to the additional water that would be acquired with available resources to further augment flows but not necessarily always meet flow targets.

Additional model runs were made to determine the impact these limitations had on bypass operations results.

3.1 Total Water Needed Calculations

When the fish rules were developed, the need for certain data for reporting was not anticipated. For example, the rules did not keep track of the total water needed for the fish at Taiban before FSID returns flows and river losses were considered.

Several problems were encountered when working with the output water needed for FSID and the fish (below Sumner) value. This value was set prior to other rules which consider if there is a spill or block release to take priority over the fish rules, but which will put water in the river. In these cases, because the water needed for FSID and the fish was not adjusted, when comparing bypasses to water needed for the fish, the calculated AWN was significantly larger than the "actual"[5] water needed for FSID and the fish.

In addition, using the previous day's loss in the Sumner to Taiban reach when calculating the water needed for FSID and the fish inflated results for days when there had been a spill or block release on the previous day which resulted in a large loss value. This also led to water needed for FSID and fish values greater than was actually necessary. To address these issues, model results were disregarded and the water needed for FSID and fish recalculated in post-processing files.

3.2 Intermittency Concerns

To evaluate the impact of FCP water on Pecos River flows, "mini" RiverWare models (as described in section 2.4) were run including an FCP of 2,500 acre-feet (af) which refilled January 1 of each year. Though the AWN calculated in post-processing files for the several alternatives (Critical Habitat, Taiban Constant and Taiban Variable LRS) was less than 2,500 af, infrequent intermittency at Acme (less than 1% of the time) occurred when a 2,500 af FCP was modeled. The Biology Work Group requested that the HWG investigate the reason for these intermittency occurrences when all requested AWN water was modeled.

3.3 Revised Fish Rules QA Simulations

To evaluate the sensitivity of model results to methods for computing channel losses in the fish rules, a quality assurance (QA) model run was performed employing a different approach to specify expected losses. The RiverWare fish rules where modified so that the previous day's loss for the Sumner to Taiban reach was replaced with the breakthrough flow for this reach. The RiverWare model was rerun with the modified fish rules for two alternatives, Acme Constant and Taiban Constant, expected to cover a range of impacts.

[5] Water needed adjusted for water in the stream resulting from block releases and spills.

After final modifications were made to post-processing files[6], the effects of the modified fish rules on Acme flows, Taiban flows, and CID supplies were examined to determine how significantly model results were impacted. Figure 6 shows exceedance curves for flows at Taiban for the Taiban Constant alternative for the "Original" (original fish rules, using previous day's loss) and "Revised" (modified fish rules, using breakthrough flows) RiverWare model runs. Figure 7 shows flow exceedance curves at Acme for the Acme Constant alternative. In both figures, the flow exceedance curves are virtually unchanged.

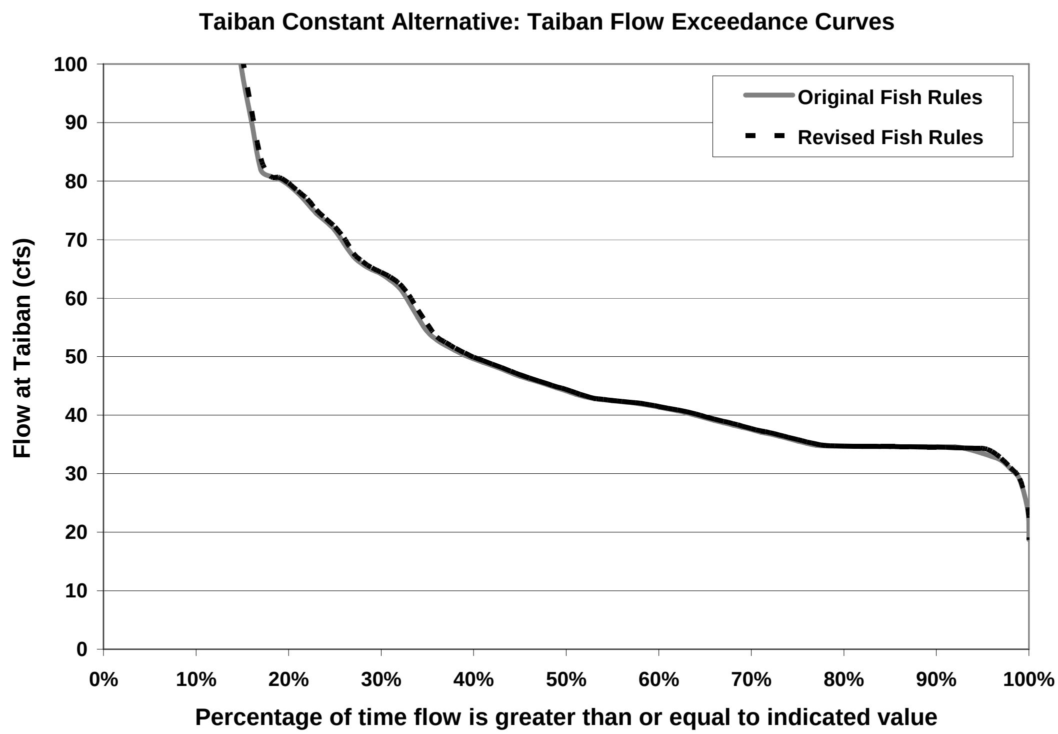

Figure 6: "Original" and "Revised" fish rule Taiban flow exceedance curves for the Taiban Constant alternative

[6] Initially it was thought that using the previous day's loss had a significant impact on the total water needed below Sumner for FSID and the fish. A comparison between exceedance curves for annual AWN volumes from RiverWare for the "Original" and "Revised" fish rule Acme Constant and Taiban Constant model runs appeared to show that the annual volume of AWN to meet fish targets increased substantially with the revised fish rules. Upon further evaluation, these differences were found to be due to inconsistent calculations being used to determine the actual water needed for the fish and AWN in post-processing files. Final changes made to post-processing calculations are documented in section 4.2 below.

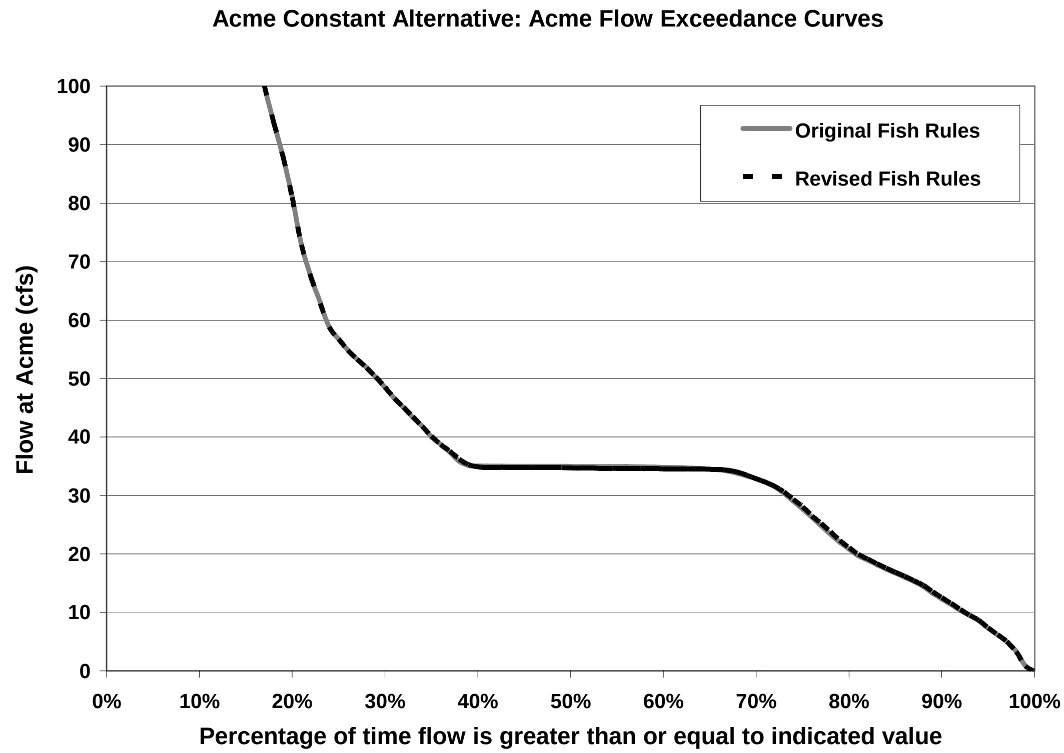

Figure 7: "Original" and "Revised" fish rules Acme flow exceedance curves for the Acme Constant alternative

Using the breakthrough flow slightly decreased intermittency (Table 1) which occurred less than 1% of the time in all model runs. The availability of water for bypasses was the limiting factor in both the "Original" and "Revised" fish rule runs.

Table 1: Intermittency Statistics at Acme for Taiban Constant and Acme Constant "Original" and "Revised" fish rule model runs.

Intermittency at Acme (intermittency defined as 0.0 cfs)				
	Taiban Constant Original Rule	Taiban Constant Revised Rule	Acme Constant Original Rule	Acme Constant Revised Rule
Percent of time intermittent	0.89	0.83	0.67	0.65
Number of days[1] intermittent	196	182	147	143

[1] *Total number of days in model runs was 21,915.*

Figures 8 and 9 show net depletions to CID for the Taiban Constant and Acme Constant Alternatives. CID net depletions are the decrease in supplies and deliveries for an alternative in comparison to the Pre-91 Baseline model run which does not include bypasses for the fish. While the differences between the original and revised fish rule runs were significant in a few years, the overall results show that changes to CID net depletions were small. The average annual CID net depletions (the results presented in the EIS) changed by only 19 acre-feet for the Taiban Constant alternative and 178 acre-feet for the Acme Constant alternative.

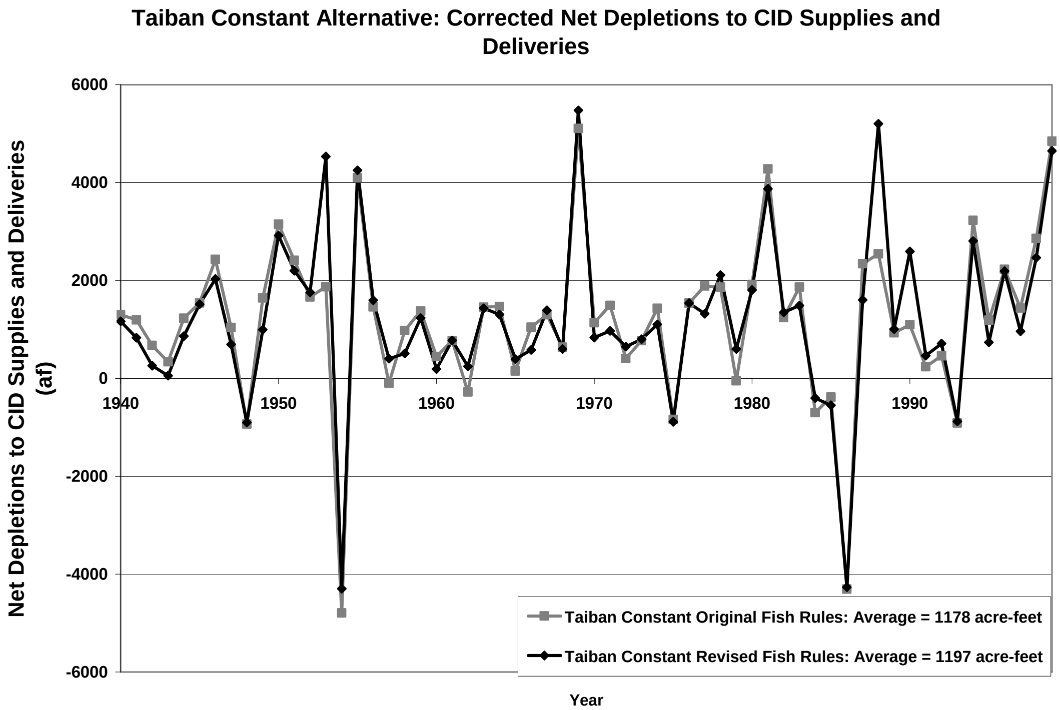

Figure 8: Annual net depletions to CID supplies and deliveries for the original Taiban Constant NEPA model run and the run with revised fish rules

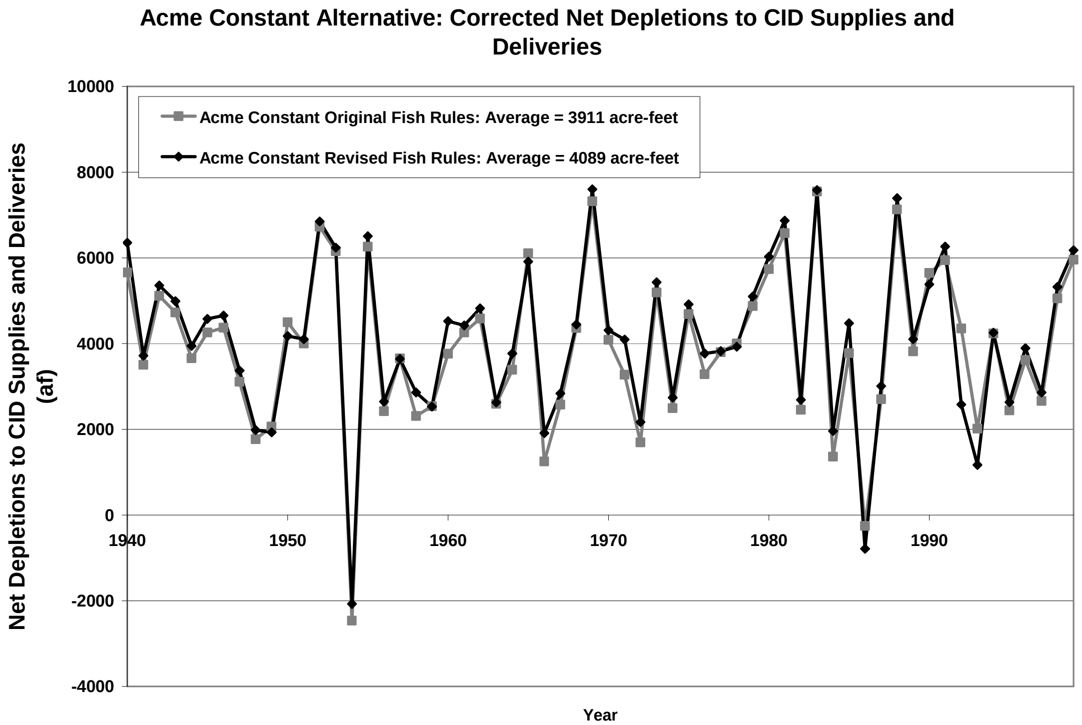

Figure 9: Annual net depletions to CID supplies and deliveries for the original Acme Constant NEPA model run and the run with revised fish rules

These results suggest that the use of the previous day's river losses in the fish rules had little impact on bypasses as the water available to be bypassed was the limiting factor.

Exceedance curves (Figure 10) show that the annual AWN for both the "Original" and "Revised" fish rule runs vary only slightly. These curves also show that initial calculations which determined that a 2,500 af FCP would be sufficient to meet target flows for the Taiban Constant alternative were erroneous, as approximately 5% of the time an FCP greater than this volume would be required.

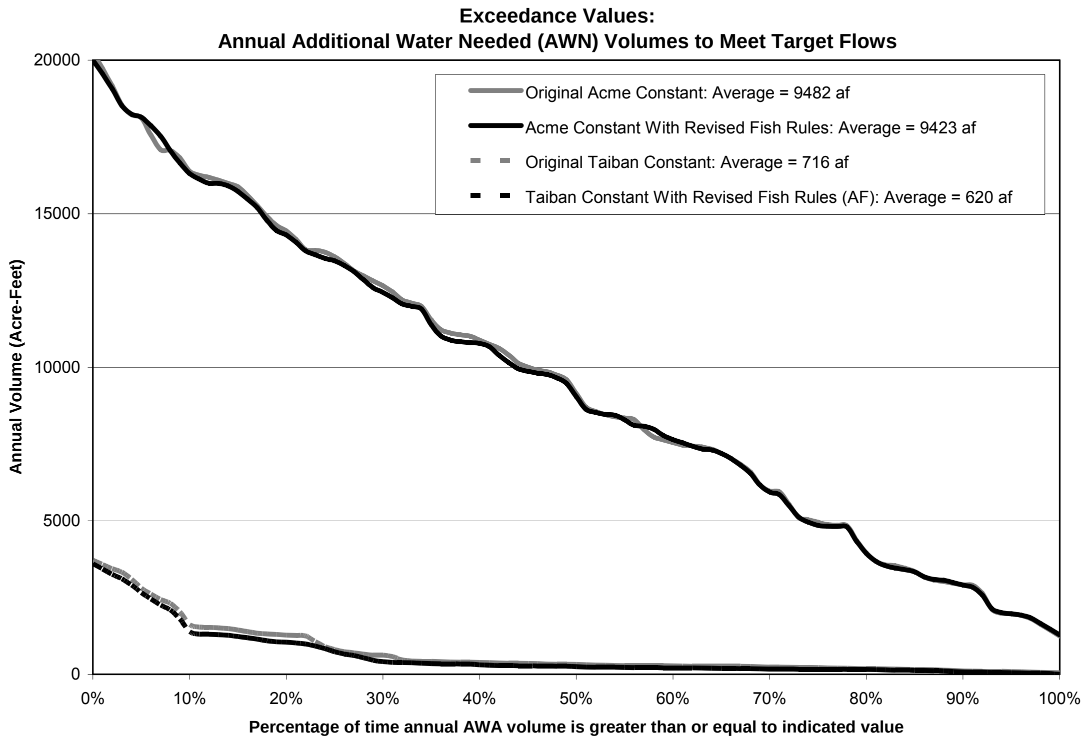

Figure 10: "Original" and "New Rule" annual additional water needed (in excess of bypasses) exceedance curves for Acme Constant and Taiban Constant alternatives

4.0 Revised Water Needed for Fish and AWN Calculations

After examining the results of the revised fish rule runs, the HWG discussed rerunning the entire PRDSS and revising bypass operations results for all of the alternatives. We decided to recalculate the correct water needed for the fish and the AWN for each alternative in post-processing files while leaving the original bypass operations results intact. This decision was made due to:

- the minimal impact on the bypass results;
- the effort which would be required to rerun the models and process results;
- the impact this would have on other work groups' schedules; and
- the overall EIS process schedule.

4.1 Rerunning Original RiverWare Models for Additional Output

To correctly calculate the actual water needed for the fish and the AWN additional data were needed (which had not been output) from the original fish rule runs. In the models, new slots were created and additional rules written to save needed data, which had originally been in the form of functions[7]. Each model was run using the original ruleset (without the revised fish rules) to insure consistency among results. The following lists the additional data which were exported from these runs and saved to the results database:

[7] In a RiverWare ruleset, functions are mathematical expressions which return temporary, unsaved information to a rule or another function for use in calculations.

- Taiban Target Series: daily Taiban target flow for alternatives with Taiban targets.
- Taiban Flow Needed for Acme Targets: daily Acme target series converted to Taiban flows for alternatives with Acme targets.
- Flow Needed at Taiban to Keep Critical Habitat Wet: daily Critical Habitat target series converted to Taiban flows for alternatives with critical habitat targets.
- Acme Target Series: daily Acme target flows for alternatives with Acme targets.
- Acme Outflow: Acme flow to check against original results to insure RiverWare models solved the same.

4.2 Post-Processing Revised Water Needed For the Fish and AWN

Separate post-processing Excel files were created for each alternative. To correctly determine the water needed for the fish (below Sumner) and AWN, several modifications were made to post-processing calculations:

- the breakthrough flow plus 1 cfs (added as buffer in the case that the flow in the river due to FSID return flows led to slightly greater losses) was used in place of the previous day's loss in the Sumner to Taiban reach;

- the water needed for the fish was adjusted so that no water was needed if there was a block release;

- if Sumner outflow was greater than 350 cfs for either of the previous two days, i.e., if Sumner was spilling, it was assumed that the reaches were still filled with water from these releases so the water needed for the fish was set to 0.0 cfs; and

- If Sumner was spilling, a check was made to see if the spills were sufficient to meet the flow target. If not, the additional water needed to be released was determined.

The following details the specific logic used in the post-processing files to determine the water needed (below Sumner) for the fish:

(1) To determine the water needed at Taiban for the fish for alternatives with critical habitat targets, the RiverWare rule (Fig. 4) which determines the Taiban target was mimicked. When the daily Acme Target Series value equaled zero, the critical habitat target was in place so the daily Taiban flow needed for the fish was set equal to the "Flow Needed at Taiban to Keep Critical Habitat Wet". Otherwise the Taiban flow needed for the fish was set equal to the "Taiban Flow Needed for Acme Targets" value.

For alternatives with Taiban targets, the water needed at Taiban for fish was set equal to the Taiban target series taken directly from the RiverWare model. For alternatives with Acme targets, the water needed at Taiban for fish was the converted Acme target taken directly from the RiverWare model.

(2) The next step was to determine the water needed (below Sumner) for the fish (Eqn. 1). If water returning to the river from FSID (return flows plus non-applied water) was greater or equal to the water needed at Taiban for fish

then no water was needed below Sumner specifically for the fish. Water returning from FSID will meet the flow target. Also, if there was a block release or large spill for any of the previous two days, i.e., Sumner outflow was greater than 350 cfs, no water needed to be released from Sumner specifically for the fish. It was assumed that enough water remained in the reach to meet the flow target. Otherwise, the water needed for the fish was calculated as the maximum of: a) 0.0 cfs (to avoid negatives) and b) water needed at Taiban for the fish plus the breakthrough flow plus 1 cfs minus water returning to the river from FSID (returns flows plus non-applied water).

Equation 1:

***Water Needed below Sumner for Fish* =**
IF *FSID Return Flow + FSID Non-Applied Water > Flow Needed at Taiban for Fish*
THEN *0.0*
ELSE
  IF *Sumner Outflow at t, t-1 or t -2 > 350 cfs*
  THEN 0.0
  ELSE
    MAXIMUM *0.0* OR *Flow Needed at Taiban for Fish + Breakthrough Flow (+ 1 cfs) – FSID Return Flow – FSID Non-Applied Water*

The resulting value was further adjusted (Eqn. 2) if Sumner was spilling to determine if Sumner outflow was sufficient to meet the fish target. If Sumner was spilling, a check was made to see if the outflow minus FSID's diversion request was greater or equal to the water needed for the fish. If it was, then no water needed to be released specifically for the fish. If it was not, then the adjusted water needed for the fish equaled the water needed below Sumner for the fish (from Eqn. 1) minus Sumner outflow in excess of FSID's diversion request. The result of these calculations was the corrected, or final, water needed for the fish.

Equation 2:

***(Final) Water Needed below Sumner for Fish* =**

IF *Sumner Storage ≥ Conservation Spill Storage Trigger*
THEN
  IF *Sumner Outflow from Bypass Model – FSID Diversion Request < Water Needed below Sumner for Fish*
  THEN *Water Needed below Sumner for Fish* - Maximum *(0.0, Sumner Outflow from Bypass Model – FSID Diversion Request*)
  ELSE
  0.0
ELSE *Water Needed below Sumner for Fish* (from Eqn. 1)

(3) To determine the daily AWN (Eqn. 3), the water bypassed for the fish (from the original bypass run) was subtracted from the final water needed for fish. What remained was the unmet need, or the AWN.

Equation 3:

AWN = Final Water Needed below Sumner for Fish – Water Bypassed for Fish from Bypass Model

(4) A revised set of Sumner outflows including bypasses and AWN water was then calculated (Eqn. 4):

Equation 4:

Sumner Outflow to Meet Fish Targets 100% of the Time = Sumner Outflow from Bypass Model + AWN

4.3 Model Simulations with AWN Added

To evaluate the effects of bypasses and AWN water on Pecos River flows, the “mini” RiverWare models from Sumner to Acme, with a simplified ruleset containing only the FSID portion of the RiverWare rules, was used. A new set of Sumner outflows was developed by adding the daily AWN (from section 4.2) to the original (bypass only) Sumner outflows. These values were imported into the mini RiverWare model and the models run for each alternative. The following data were exported: Sumner outflows (QA/QC to insure correct input values were used in run), Sumner to Taiban gain/loss, Taiban flow, Dunlap flow and Acme flow.

Revised water needed for the fish, AWN values, and "mini" model results were imported into the database, AWN and flow exceedance curves and intermittency statistics generated, and results delivered to EIS work groups.

5.0 Modeling and Post-Processing Results

This section summarizes results for a few key hydrologic resource indicators. More detailed descriptions of resource indicators and the analysis results are described in the EIS.

5.1 Bypass Operations Only

The magnitude and variability of flows in the Pecos River strongly impact the health of the PBNS population. Perhaps the most important measure with regard to the PBNS is the flow at the Acme gage. The Acme gage is located 26 miles downstream from the Upper Critical Habitat reach for the PBNS, and it is also along the reach just upstream of Acme that the river is most susceptible to intermittency.

Flow exceedance curves were used to measure flow changes at Acme for impact analysis. Flow exceedance curves show the probability that the average daily flow will exceed any given value. Figure 11 shows flow frequency curves at Acme for each alternative, when using Sumner bypass water only. In the lower flow ranges (less than

50 cfs), alternatives with higher flow targets (e.g., the Acme Constant alternative) tend to exhibit higher flows at the Acme gage.

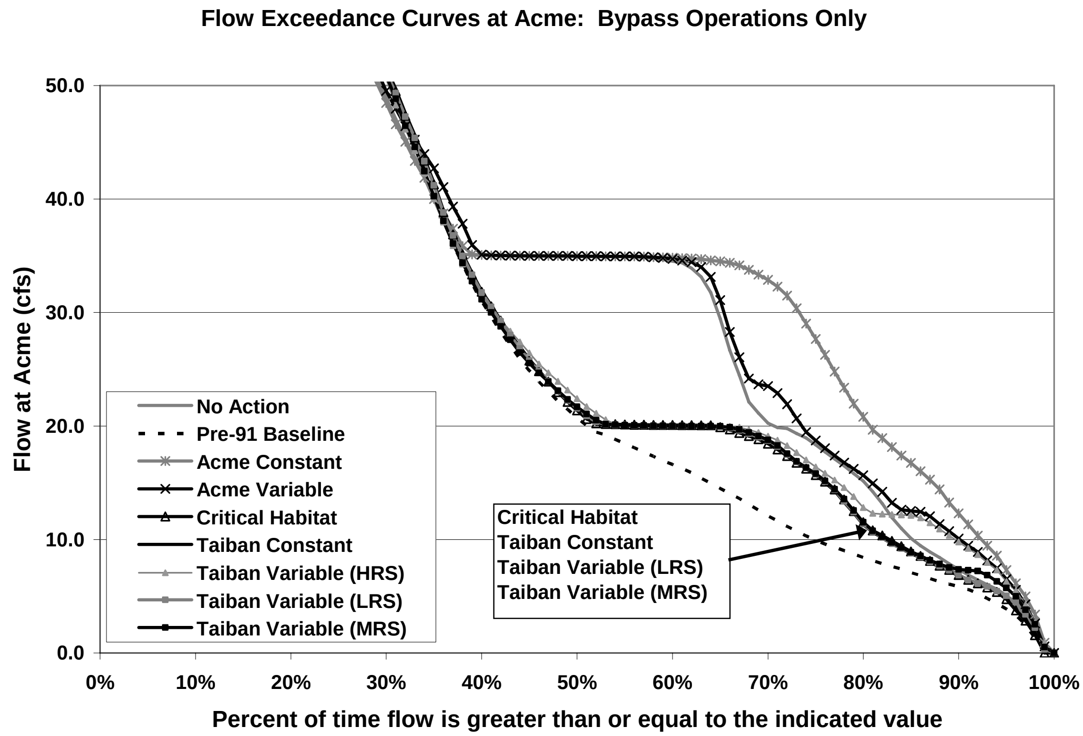

Figure 11: Flow exceedance curves at Acme for alternatives with bypass operations only

When bypass operations are used to meet the flow targets, intermittency (Table 2) occurred under all alternatives, ranging from a low of 0.67% of the time for the Acme Constant alternative to 1.07% of the time for the Critical Habitat alternative. Intermittency occurred 1.20% of the time for the Pre-91 Baseline.

Table 2: Acme intermittency statistic for bypass operation only (no AWN available)

Intermittency defined as Acme flow = **0.0 cfs**									
	No Action	**Pre-91 Baseline**	**Acme Constant**	**Acme Variable**	**Critical Habitat**	**Taiban Constant**	**Taiban Variable (55 cfs)**	**Taiban Variable (40 cfs)**	**Taiban Variable (45 cfs)**
Percent of Time Intermittent	0.94	1.20	0.67	0.68	1.07	0.89	0.63	0.85	0.80
Total # Intermittent Days	205	263	147	150	234	196	137	187	176
Total # Days in Run	21915	21915	21915	21915	21915	21915	21915	21915	21915
Number of Consecutively Intermittent Days									
1 day	1	4	3	4	2	6	1	2	1
2 to 5 days	10	8	2	3	10	5	4	6	5
6 to 10 days	5	9	5	5	8	6	6	5	7
11 to 20 days	2	3	2	3	3	2	3	2	2
21 to 30 days	3	5	3	2	4	4	1	4	3
> 30 days	1	0	0	0	0	0	0	0	0

5.2 *Bypass Operations with AWN*

Table 3 shows average values for the water needed for the fish, water that was bypassed for the fish, and AWN to meet flow targets. It is important to note that in any given year, these values can vary greatly. For example, the average annual AWN ±1 standard deviation is presented. Standard deviations are large, and for several alternatives are equal to or greater than the average values. A strong correlation between the flow target magnitude and the amount of additional water needed to meet that target is evident.

Table 3: Average annual water needed for the fish: total, bypassed and AWN

Alternative	Average Annual Volumes[1] (acre-ft)			
	Total Water Needed	Available Water that was Bypassed	Additional Water Needed[2] (AWN)	AWN ±1 Standard Deviation
Taiban Constant	2600	1900	700	700 ±900
Taiban Variable (LRS cfs)	3600	2200	1400	1400 ±1500
Taiban Variable (MRS cfs)	5600	3200	2400	2400 ±1800
Taiban Variable (HRS cfs)	9000	4800	4200	4200 ±2700
Acme Constant	22500	13000	9500	9500 ±5200
Acme Variable	15000	9700	5300	5300 ±3300
Critical Habitat	2700	2100	600	600 ±700
No Action	10700	7800	2900	2900 ±2900

[1] All values are rounded to the nearest 100 acre-feet.
[2] AWN is the additional water needed, in addition to bypasses, to meet flow targets 100% of the time.

Figure 12 shows exceedance curves for the annual additional water needed for each alternative. The volumes vary greatly, with the highest required AWN for each alternative occurring only a small percentage of the time. The Acme Constant alternative stands out as requiring by far the largest AWN, followed by the Acme Variable alternative. The extremely variable nature of annual AWN requirements should be addressed as options for additional water acquisition are considered.

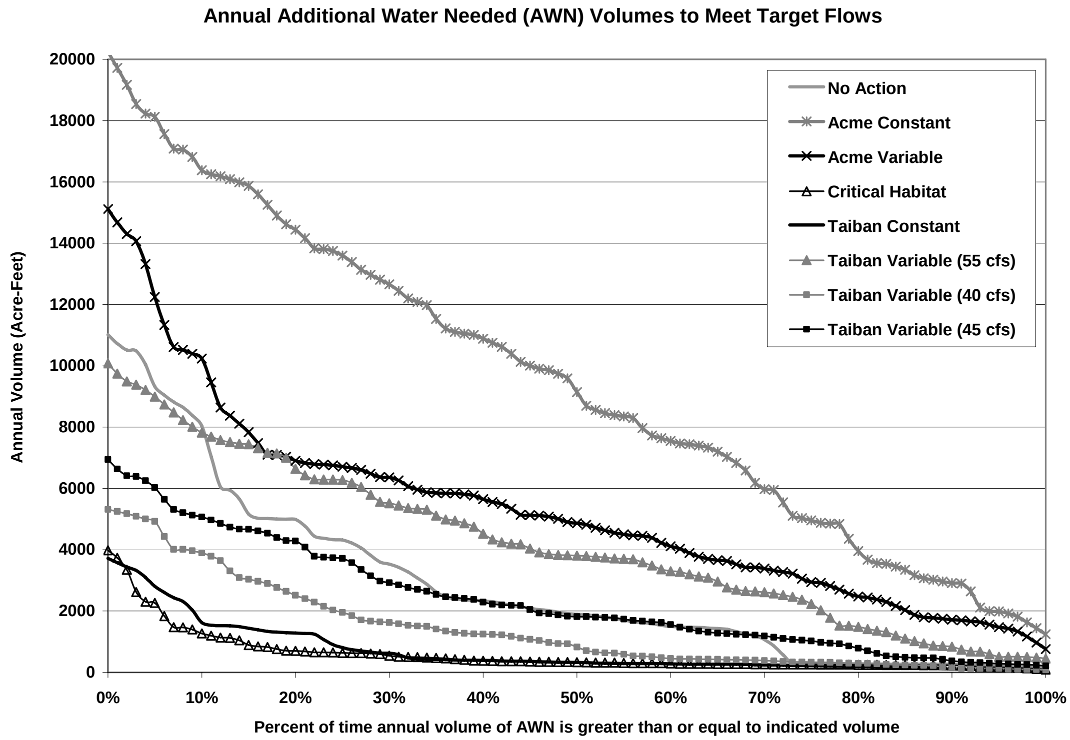

Figure 12: Annual additional water needed below Sumner Reservoir for the fish exceedance curves

Figure 13 shows how bypasses combined with AWN water effect Acme flows. For example, target flows for the 35 cfs Acme Constant alternative are met nearly all of the time. The small percent of the time when target flows are not met is due to the model being unable to exactly predict downstream flows when determining the water needed below Sumner to meet targets.

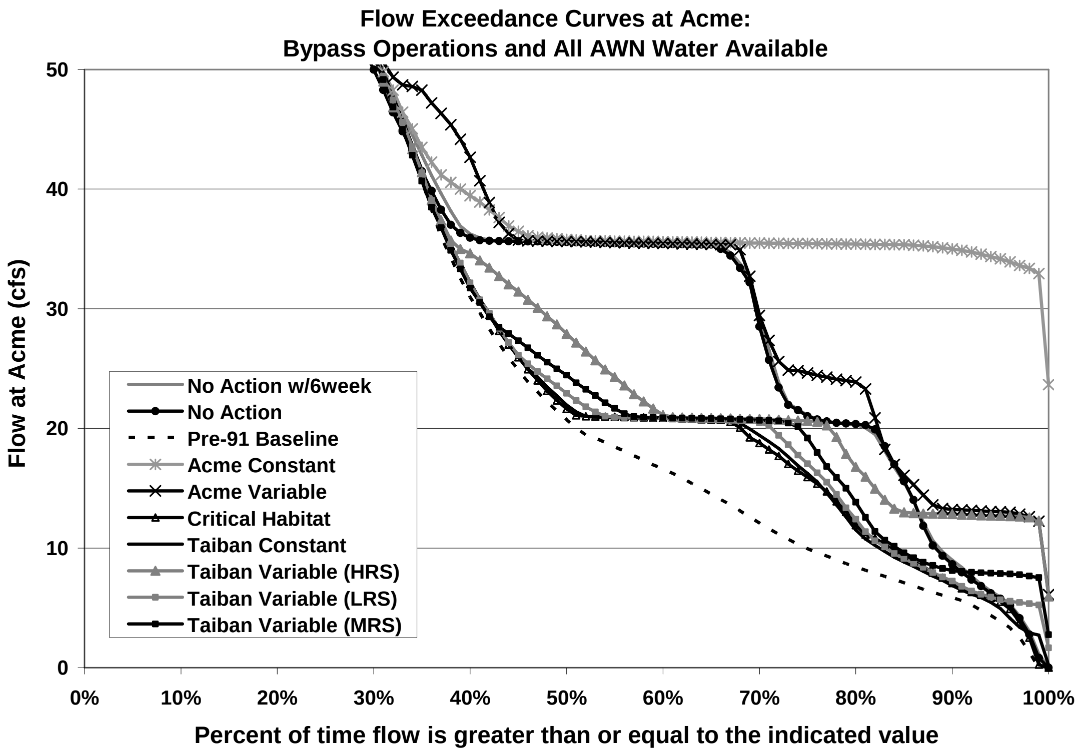

Figure 13: Flow exceedance curves at Acme for alternatives with bypass operations and all AWN available

Intermittency statistics are presented in Table 4. When AWN water is added to bypass water, intermittency at Acme only occurred for the No Action and Critical Habitat alternatives when the flow target was for the Critical Habitat, a more upstream reach. For all other alternatives, no intermittency occurred with AWN water.

Table 4 : Acme intermittency statistic for bypass operation with all AWN available

Intermittency defined as Acme flow = **0.0 cfs**									
	No Action	**Pre-91 Baseline**	**Acme Constant**	**Acme Variable**	**Critical Habitat**	**Taiban Constant**	**Taiban Variable (HRS)**	**Taiban Variable (LRS)**	**Taiban Variable (MRS)**
Percent of Time Intermittent	0.72	1.20	0.00	0.00	0.85	0.00	0.00	0.00	0.00
Total # Intermittent Days	158	263	0	0	187	0	0	0	0
Total # Days in Run	21915	21915	21915	21915	21915	21915	21915	21915	21915
Number of Consecutively Intermittent Days									
1 day	1	4	0	0	2	0	0	0	0
2 to 5 days	10	8	0	0	9	0	0	0	0
6 to 10 days	4	9	0	0	7	0	0	0	0
11 to 20 days	3	3	0	0	2	0	0	0	0
21 to 30 days	2	5	0	0	3	0	0	0	0
> 30 days	0	0	0	0	0	0	0	0	0

6.0 Note on Water Needed for the Fish as Reported

As discussed in Section 3, the HWG decided not to rerun the bypass only simulations with the revised fish rules because the impacts on bypasses were minimal. As a result, the original modeled bypasses for the fish are reported in results files while the water needed below for fish was recalculated in post-processing files. The revised results led to infrequent times in the original simulations when water was bypassed for the fish though it was not needed. There were also infrequent times when additional water was available, and should have been bypassed, but was not. The overall result is that the sum of annual water bypassed for the fish (from the original bypass runs) plus the annual AWN (as calculated in post-processing files) is greater than the annual water needed for fish which was calculated in post-processing files. Table 5 presents the differences between the calculated water needed for the fish and sum of bypasses and calculated AWN water. The greatest annual discrepancy was 443 acre-feet for the Taiban Variable (45 cfs) alternative, which also had the greatest average annual difference of 117 acre-feet.

Table 5: : Annual differences between a) annual water needed below Sumner for fish and b) annual bypasses plus annual AWN

Annual Water Needed below Sumner for Fish - [Annual Water Bypassed for Fish + Annual AWN Water] (acre-feet)								
50 year	No Action	Acme Constant	Acme Variable	Critical Habitat	Taiban Constant	Taiban Variable (55 cfs)	Taiban Variable (40 cfs)	Taiban Variable (45cfs)
Maximum	0	0	0	0	0	0	0	0
Average	-14	-18	-26	-61	-32	-27	-89	-117
Minimum	-104	-53	-226	-344	-214	-250	-362	-443
Annual Water Needed Below Sumner For Fish (acre-feet)								
Average	10645	22512	15023	2638	2569	9019	3538	5456

In response to these discrepancies and to insure results mass-balanced, the water needed for fish was reported (Table 3) as the sum of bypasses and AWN (rather than as the water needed for fish as calculated in the post-processing files). Because these values are higher than the post-processed water needed for the fish, results slightly overestimate the total annual volume of water needed to meet fish targets.

7.0 Summary of Caveats and Considerations for Future Model Runs

For future NEPA PRDSS simulations, the following should be considered as potential edits to the fish rules:

1. Rewrite the fish rules to mimic the revisions described in this document.
2. Create new slots and rules to save additional values used in fish rule calculations.
3. Apply losses to local inflows above Sumner when determining water available for bypasses. Currently no loss is applied to these values.
4. Use the actual loss[8] from Sumner to Taiban instead of the breakthrough flow + 1 cfs.
5. Include side inflows in reaches above the flow target locations when calculating the water needed for the fish.
6. Use a two week average of local inflows available when calculating "available water" for the fish as is currently done by operators in the actual Pecos River system. If this is done, it should be noted that if FSID is not getting their full diversion right, they can divert water bypassed for fish up to their full right. This would require completely rewriting the fish rules.

[8] Since bypass modeling was completed, Tetra Tech, Inc. has further refined Sumner to Taiban loss calculations by developing a loss relationship from Sumner to Taiban for use in the RiverWare rules.

7. Consider additional refinements in modeling to simplify and/or eliminate much of post-processing calculations.

8.0 Summary and Conclusions

This document describes NEPA alternative bypass operations modeling, fish rule concerns, and additional modeling and post-processing to back out additional results necessary to evaluate alternative impacts on resource indicators. Summary results are presented for bypass operations with and without AWN water. Though the fish rules were found to have certain limitations, bypass operations results were impacted only slightly with revised rules because the availability of water to be bypassed was the limiting factor. Total water needed for fish and AWN values were impacted by the fish rules edits. Rather than rerun all alternatives models, needed values were backed out in post-processing files. Simplified model runs were made to evaluate the impact of runs with bypass and AWN on Pecos River flows to Acme.

9.0 References

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Tetra Tech, Inc., 2003b. Pecos River RiverWare Model Report, Volume II, Appendix F: Detailed Rule Descriptions and Documentation. Internal Work Group Draft.

ATTACHMENT A: Summary Alternative Matrix

Carlsbad Project Water Operations and Water Supply Conservation EIS Alternatives												
	{-----------------Range of Flows ----------------------}						{----------------------------------Block Releases--------------------------------}					
	{-----Dry-----}		{-----Average-----}		{---Wet---}							
Alternative Designation	**Winter Target**	**Summer Target**	**Winter Target**	**Summer Target**	**Winter Target**	**Summer Target**	**Duration**	**Frequency**	**Magnitude**	**Ramp Down**	**Delivery**	**Time of Year**
Taiban Constant	35 cfs @ Taiban	35 cfs @ Taiban. Use pumps to prevent intermittency @ Acme	35 cfs @ Taiban	35 cfs @ Taiban. Use pumps to prevent intermittency @ Acme	35 cfs @ Taiban	35 cfs @ Taiban. Use pumps to prevent intermittency @ Acme	15 day max	On CID demand, but space out as long as possible	On CID demand	None	Maximum Efficiency	On CID demand – avoid releases during 6 weeks around August 1st
Taiban Variable	35 cfs @ Taiban	45cfs, -5, +10 @Taiban.	35 cfs @ Taiban	45cfs, -5, +10 @Taiban.	35 cfs @ Taiban	45cfs, -5, +10 @Taiban.	15 day max	On CID demand, but space out as long as possible	On CID demand	None	Maximum Efficiency	On CID demand – avoid releases during 6 weeks around August 1st
Acme Constant	35 cfs Acme	35 cfs Acme	35 cfs Acme	35 cfs Acme	35 cfs Acme	35 cfs Acme	15 day max	On CID demand, but space out as long as possible	On CID demand	None	Maximum Efficiency	On CID demand – avoid releases during 6 weeks around August 1st
Acme Variable	35 cfs Acme	12 cfs Acme	35 cfs Acme	24 cfs Acme	35 cfs Acme	48 cfs Acme	15 day max	On CID demand, but space out as long as possible	On CID demand	None	Maximum Efficiency	On CID demand – avoid releases during 6 weeks around August 1st
Critical Habitat	35 cfs Taiban Minimum	Critical Habitat Kept Wet; Avoid Intermittency @ Acme	35 cfs Taiban Minimum	5 cfs Acme	35 cfs Taiban Minimum	10 cfs Acme	15 day max	On CID demand, but space out as long as possible	On CID demand	None	Maximum Efficiency	On CID demand – avoid releases during 6 weeks around August 1st
No Action (Current Operations, 2003-2006 Biological Opinion)	35 cfs Acme	Upper Critical Habitat Kept Wet; Avoid Intermittency @ Acme	35 cfs Acme	20 cfs Acme	35 cfs Acme	35 cfs Acme	15 day max at peak. 65 days per year.	Space out to 14 + days apart	1200 cfs	None	Maximum Efficiency	No winter. On CID demand

Notes:

Reflects screening by the Alternatives Workgroup on 9/18/03 with 9/24/03 input from the Biology Workgroup and changes from 12/04/03 meeting.

Screening focused on flows and releases. Specific habitat restoration and conservation measures were not evaluated.

Unless specified differently in an alternative, all alternatives would have the following actions incorporated: (Some may require additional project-specific NEPA analysis)

- ✓ Offset all depletions through actions and priorities developed by the WOOG Group.
- ✓ Establishment and management of a conservation pool in Fort Sumner and Santa Rosa Reservoirs.
- ✓ Creation of a management plan addressing monitoring of the flow targets and establishing procedures, mitigative actions and sources of water available in case flow targets are threatened.
- ✓ Execution of an agreement document among the agencies governing the conservation pool and adaptive management plan

The following conservation actions would be considered by the appropriate agencies: (Some may require additional project-specific NEPA analysis)

- ✓ Continue to develop wells and pumping infrastructure to respond for the need to supplement flows in the short-term.
- ✓ Continue to remove non-native riparian vegetation.
- ✓ Restore natural channels to provide better riparian habitat.

*Net Depletions are calculated by comparing to historic, pre-fish operations

Pecos River RiverWare Model
CPWA Modeling Documentation Report

Report on Modeling Assumptions and Output Analysis for Determination of Effective CPWA Amounts

January 2006 Final Report

Stockton Engineering

TETRA TECH, INC.

1.0 Introduction

This report documents the use of the Pecos River RiverWare Model (Tetra Tech, 2003b, 2003d, 2000b) to study the effects of Carlsbad Project Water Acquisition (CPWA) options on selected resource indicators identified for the ongoing Carlsbad Project Water Operations and Water Supply Conservation Environmental Impact Statement (Carlsbad Project EIS). This report contains model results concerning the effectiveness of the CPWA options recommended by the Water Offset Options Group (WOOG) as the most viable options that could be implemented within 3 years of completion of this EIS (designated as the "A" list of CPWA Options).

1.1 Carlsbad Project Water Acquisition Options—Definition

CPWA options are explicitly designated for the purpose of eliminating net depletions to the Carlsbad Irrigation District (CID) caused by the reoperation of Sumner Dam for the Pecos bluntnose shiner (PBNS). Changes to CID supply from bypass operations primarily come from three sources: loss in transmission efficiency caused by bypass operations through Sumner Dam, increased or saved reservoir evaporation from the average differences in reservoir storage configurations, and increased conservation spills from Avalon Reservoir. From a WOOG perspective, the purpose of these options is solely to "keep CID whole", as is stated in the purpose and need for the Carlsbad Project EIS. The goal of the CPWA modeling was to quantify the effectiveness of each option in eliminating net depletions to CID supply since the original amounts identified by the WOOG only indicated the amount available at the source. Modeling of the CPWA options accounts for CID water operations and is a good indication of the amount of water available to CID considering the source of the option, its transmission efficiency, evaporative losses and savings, and timing.

1.2 CPWA—Modeled Options

CPWA options were compiled, examined and ranked qualitatively and quantitatively by the WOOG for their suitability to eliminate net depletions to CID (Reclamation, 2005b). The results of the ranking were two ordered lists, an "A" and a "B" list. Each list contains the options ranked from most viable to least viable. The "A" list contains options that are estimated to be implemented in a 3-year time horizon. The "B" list contains all of the remaining options identified by the WOOG. For efficiency and given the scope of this EIS, it was decided that only the "A" list options would be examined in detail using the alternative models and the "B" list options would be given a more qualitative hydrologic evaluation. The A-list modeled options along with their modeled amounts of water to be acquired are shown in Table 1. For options D and E, purchase and lease numbers, as provided by the WOOG and shown in the table (with the exceptions of D-1B, D-1BX, and D-1E, which have one extra permutation), were aggregated to form larger amounts from the same agricultural source. For these cases, it was assumed half of the water would be obtained through purchase, and the other half of the water would be obtained by renewing leases over the 60-year modeling period. The amounts shown for the CID cropping pattern and retirement options represent the maximum savings possible based on a full annual allotment for CID, which does not occur every year.

Table 1. A-List CPWA Options and Their Average Annual Modeled Amounts

CPWA Option Designation(s)	CPWA Option	Modeled CPWA Amounts (acre-ft/year) [1]
D-1A, D-1AX, and E-1A	Surface Water Right Purchase in FSID	1,500 3,100 [2]
D-1B, D-1BX, and E-1B	Surface Water Right Purchase in PVACD (River Pumpers)	1,600 2,250 4,215 [2]
D-1C, D-1CX, and E-1C	Surface Water Right Purchase in CID	5,550 11,100 [2 & 2]
L	Change Cropping Patterns in CID – ranging from very low to medium crop irrigation requirements (relative to alfalfa crop requirement)	6,000 to 10,500 [3]
Q1-SR	Seven Rivers Well Field	10,000 [4]
Q1-BV	Buffalo Valley Well Field	10,000 [4]
U	Fort Sumner Gravel Pit Pumping	300

[1] From WOOG analyses; see Southwest Water Consultants and Tetra Tech, Inc. (2004).
[2] Larger number represents amount available through both purchase and lease; diversion amounts shown.
[3] Assumes maximum CID allotment for the entire irrigation season; theoretical maximums shown.
[4] Retired or leased consumptive use amount—well field maximum annual pumping capacity subject to groundwater right administration.

2.0 Explanation of CPWA Options with Modeling Assumptions

The following sub-sections explain modeling assumptions associated with the investigation of each A-list CPWA option shown in Table 1. Modeled amounts for retirement and leasing scenarios were converted to diversion amounts where appropriate from the original consumptive use values (amounts available) indicated by the WOOG. The remaining options utilized direct WOOG estimates for amounts available; but depending on the option, this amount may not be realized due to limiting constraints explained in each sub-section.

2.1 FSID Lease and Purchase

The FSID retirement scenarios, CPWA Options D-1A, D-1AX, and E-1A, consisted of retiring and leasing a portion of FSID's irrigated acreage and holding that water back in Sumner Reservoir for CID to deliver to Brantley Reservoir in a block release. Since FSID's average diversion and irrigated acreage does not correspond to usual farm deliveries of 3.0 acre-feet/acre for water right administration, retirement was based upon an average CPWA forbearance amount and the corresponding acreage was retired on a percentage basis. Annual FSID forbearance amounts for CPWA included 1,500 acre-ft/year and 3,100 acre-ft/year. Retired acreages corresponding to those amounts, which were reduced for the algorithm determining return flow, were 190 and 380 acres, respectively. Pump back flows were not reduced in the FSID return flow method.

2.2 River Pumper Lease and Purchase

CPWA Options D-1B, D-1BX, and E-1B, represent surface water retirement of diverters in the vicinity of or within the Pecos Valley Artesian Conservancy District (PVACD), which are more commonly referred to as “river pumpers”. River pumpers take their diversions from the Pecos River by pumping directly from the river. Three diversion amounts were investigated for the river pumper lease and purchase modeling scenarios including retirement or lease of 1,600, 2,250, and 4,215 AF/year.

These CPWA options were implemented by curbing river pumper diversions within the Pecos River RiverWare model. The daily diversions were reduced by subtracting the Pre-91 daily diversion amount times the ratio of the retirement scenario (using the annual amount of Pre-91 diverters—4,215 AF/year—to obtain the ratio) from the Pre-91 daily diversion. The 4,215 AF reduction represents retirement of most of the remaining active diverters that have not been bought out completely.

Return flows were modeled as 40% of the diversion amounts. Given the proximity of the river pumpers place of use to the Pecos River and a modeling period of 60-years, no lag is applied to the return flows and they are immediately added back to the river at the same time-step the diversion was subtracted.

2.3 CID Lease and Purchase

Purchase and lease CPWA options within CID, CPWA options D-1C, D-1CX, and E-1C, consisted of three different model methods for estimating effective CPWA amounts:

- The first consisted of only curbing the “actual irrigated acreage” in the model. This scenario represented the minimum possible amount available for eliminating net depletions to CID.
- The second method consisted of also reducing the “total irrigable acreage” by a constant amount in addition to the “actual irrigated acreage”. In other words, if the “actual irrigated acreage” was reduced by 3,000 acres then the “total irrigable acreage” was also reduced by 3,000 acres.
- The third scenario consisted of reducing the “actual irrigated acreage” (by the estimated retirement amount) and reducing the “total irrigable acreage” by the ratio of the “total irrigable acreage” / ”actual irrigated acreage” (25,055 acres/20,000 acres) times the estimated retirement amount. In other words, if the “actual irrigated acreage” was reduced by 3,000 acres then the “total irrigable acreage” was reduced by 25,055/20,000 * 3,000 = 3760 acres.

“Actual irrigated acreage” is used to determine the diversion in the RiverWare model while “total irrigable acreage” is used to set the diversion amount per acre for CID irrigators in the RiverWare model. The effect on the algorithm from reducing the “actual irrigated acreage” is more water becomes available in storage and is included in setting the amount diverted per acre. Reducing the “total irrigable acreage” has the same effect by also increasing the amount of water that each farmer is able to divert per acre. Both reductions simulate the redistribution of retired or leased water rights onto the remaining farms.

2.4 Cropping Pattern Changes

Cropping pattern changes within the CID were also modeled by limiting farm headgate delivery volumes from 0.7 ft to 2.0 ft per irrigated acre dependent on crop type. Originally, volumes were meant to correspond to replacement crop types from small grain to sorghum or corn compared to alfalfa. During the WOOG process the water from the required diversion amounts for these crop types were developed by comparing the farm delivery requirement (including annual rainfall and soil leaching requirements) to the typical farm delivery requirement in the Carlsbad area for alfalfa, which amounts to 4.5 acre-ft per acre (Brummer, 2003). However, since the average normalized diversion per acre at the farm headgate for the pre-91 baseline simulation was only 2.8 acre-ft/acre, the savings identified by the WOOG, shown in Table 1, were overestimated. In addition, the comparison of the water savings identified by the WOOG to a maximum farm delivery of 3.7 acre-ft/acre to compute maximum cropping pattern deliveries at the farm headgate led to an underestimation of crop irrigation requirements for the aforementioned crop types. For these reasons, the crop names were dissociated from the modeled farm delivery amounts and the headgate delivery volumes were used to represent the conversion to lower-water-use crops.

For all of the cropping pattern CPWA scenarios, replacement acreage of 5,000 acres was used. Those 5,000 acres of replacement crops were modeled by limiting the maximum farm delivery per acre on the 5,000 acres. Those maximum amounts (at the farm headgate) are shown in the second column of Table 2. The third column in Table 2 shows the amount limited at the diversion of the CID main headgate from Avalon Dam. These amounts include a transmission efficiency of 74.6% to the farm headgates. Modeled cropping pattern changes within the CID also did not include changes to the “irrigable acres” in the algorithm in an attempt to simulate redistribution of saved water to the remaining farmers.

Table 2. Maximum Deliveries at the Farm Headgate and Maximum Diversions at Avalon Dam for Cropping Pattern CPWA Simulations

Range of Relative Water Use of Replacement Crop Type	Maximum Delivery at Farm Headgate (acre-ft/acre)	Maximum Diversion at Avalon Dam (acre-ft/acre)
Very Low	0.7	0.9
Low	1.2	1.6
Medium	2.0	2.7
(pre-91 for comparison)	3.7 [1]	5.0 [1]

[1] Full allotments for CID do not occur every year. In the pre-91 simulation, a full allotment only occurred in the modeled year 1942; diversions at Avalon Dam exceeded 4.9 acre-ft/acre (nearly full allotments) in modeled years: 1942, 1943, 1958, 1987, 1992, and 1998. The average 60-year diversion at Avalon Dam for the Pre-91 simulation was 3.7 acre-ft/acre (2.8 acre-ft/acre at the farm headgate).

2.5 Well Field Pumping – Lagged Month Pumping at Seven Rivers or Buffalo Valley

Pumping from a well field was modeled to simulate the effects of retiring pumping rights in the PVACD and using those rights to pump water to augment CID supply. Two different scenarios were investigated including a well field located near Buffalo Valley and a well field located near

Seven Rivers. The scenarios were simulated using “lagged month” pumping, which summed all of the daily bypass volumes from the previous month and estimated the depletions for that month as 50% of the bypass volume. Included with the 50% depletion estimates were transit losses, which were modeled as 5% of the pumped CPWA flow for Seven Rivers and 15% of the pumped CPWA flow for Buffalo Valley. Well field diversions for the current month target the estimated depletions for the previous month plus any carry over estimated depletion amount from the month before the previous month. This was implemented since the well field capacity did not always meet or exceed the estimated monthly depletion. The well fields were modeled assuming 10,000 AF of consumptive use retirement in PVACD. The well fields were assumed to have an annual pumping capacity of 12,100 AF/year or 33.14 AF/day. The Pecos River RiverWare model was used to compute the initial pumping amounts, and the Roswell Artesian Basin Groundwater Model—RABGW (DBS&A, 1995; Keyes, 2000; SSPA, 2003; Hydrosphere, 2003c) was used (in collaboration with Hydrosphere and the NMISC) to model the base inflow change from Acme to Artesia resulting from the retired acreage in PVACD and the pumping used to eliminate net depletions to CID. These base inflows were then input into the RiverWare model once again, and the final model simulation was made to incorporate all the effects of the CPWA option. Using this methodology, pumping amounts changed less than 6% by the second iteration (after base inflow accretion due to retirement), which was deemed satisfactory for convergence.

2.6 Gravel Pit Pumping

Near Ft. Sumner, NM is a large gravel pit that accumulates groundwater. It is estimated that this gravel pit has nearly 300 AF/year of inflow. Pumping from the gravel pit was modeled with the RiverWare model by assuming a constant inflow of 300 AF/year to the pit and adding up to 300 AF/year to the river at the Taiban node whenever flows in the river were at or above 350 cfs. By supplementing larger flows with gravel pit pumping, it was anticipated that the gravel pit pumping would be more effective as a CPWA option. Pumping was switched on with a 350 cfs Sumner outflow trigger, but typically pumping was initiated during flood flows and block releases if adequate supply was available in the pit. Rates of pumping from the pit were simulated at 10 AF/day and 20 AF/day.

2.7 Modeled Alternatives and Assumption of Superposition

Due to the large number of permutations of model simulations required when matching each A-list WOOG option with the six alternatives and the pre-91 baseline, only the pre-91 baseline (no depletion), Acme Constant (most depletive alternative), and Taiban Constant (least depletive alternative) alternatives were simulated with A-list CPWA options. This cut the amount of modeling by more than half. By grouping the permutations this way, it was assumed that results from the two alternatives could be superimposed upon the remaining alternatives. Conclusions concerning this assumption are summarized in Section 3.4.

3.0 CPWA Options Modeling Results

This section presents a summary of CPWA modeling results along with analysis tools used to isolate effective CPWA amounts. Section 3.1 presents a summary of analysis tools. Sub-section 3.1.1 provides references for basic definitions for net depletion components, sub-section 3.1.2 shows definitions for CPWA components, sub-section 3.1.3 identifies sources for ineffective portions of CPWA, and section 3.1.4 provides estimates for CPWA Brantley transit efficiencies. Section 3.2 presents summary annual average results using the analysis tools defined in Section 3.1. Section 3.3 provides detailed results. Sub-section 3.3.1 provides

Brantley transit efficiency results, sub-section 3.3.2 shows detailed daily examples of effective CPWA and net depletions for select years and non-Project derived CPWA options, and sub-section 3.3.3 presents cumulative effective CPWA figures for non-Project derived CPWA options. Sub-section 3.3.4 presents daily effective CPWA derived from Project supply, and sub-section 3.3.5 shows cumulative 60-year Project derived CPWA results. Sub-section 3.3.6 reconciles ineffective Project CPWA results, and sub-section 3.3.7 presents correlations between theoretical CPWA amounts and ineffective CPWA due to spills from the system. Finally section 3.4 summarizes conclusions regarding superposition of CPWA results onto alternatives that weren't modeled with CPWA options.

3.1 Summary of Analysis Tools

Analysis tools to isolate effective CPWA from model output are defined and explained in the following sub-sections. These analysis tools include use of the "net depletion" calculation, which is simply a comparison of a model output parameter or multiple model output parameters between two model runs. Net depletions to CID are useful in determining effectiveness of CPWA for non-Project related CPWA options, such as forbearance in the FSID. For Project related CPWA options, such as retirement in CID, effective allotments and normalized daily diversions, which are based on diversion amounts and remaining irrigated acreage, are used to calculate effective CPWA to CID to eliminate net depletions to CID.

3.1.1 Definition of Net Depletion Terms

In general the net depletions to CID and the subsequent calculation of non-Project effective CPWA at the diversion are presented in this memorandum three different ways including:

- corrected reoperation net depletions to CID,
- reoperation net depletions to CID,
- and net depletions at the CID main.

For further information and derivations of net depletions to CID, please refer to the memorandum titled "Carlsbad Project Supply Net Depletion Calculations with Avalon Spill Variability Removed" (Tetra Tech, 2003e), and also refer to the memorandum titled "Results Memorandum for Alternative Modeling Using Bypass Water" (Briggs et al., 2005). Additional transmission depletions and saved reservoir evaporation are only presented in the Project derived mass balance section (3.3.6) and to develop the Brantley transit efficiencies shown in section 3.3.1; however, mass balance using transmission depletions and saved evaporation was calculated for every CPWA option. Due to the large amount of information that would need to be presented, these mass balance values are not presented here, but are documented as part of the administrative record of this EIS.

3.1.2 Definition of CPWA Terms

CPWA options follow the same terminology as net depletions for non-Project CPWA options since the effectiveness of the CPWA option must be derived from the net depletion results. Four computation methods for effectiveness of CPWA options are presented in this report. These include the non-Project CPWA options, which are computed using the corrected reoperation net depletion to CID, the reoperation net depletion to CID, and the net depletion at the CID main. The fourth method applies to Project derived CPWA options. It determines the additional amount diverted to the remaining farmers, which is the effective CPWA for these options. It should be clarified that the Project CPWA options were measured as diversions from

Avalon Dam at the CID main and not diversions to the farm field itself. Also presented in this report with the (average) effective CPWA is the theoretical CPWA. This is the annual average amount of water added to the system. This number is always larger than any of the four other aforementioned effective CPWA amounts. For various reasons, including portions of CPWA lost to conveyance losses to Avalon from the point where the CPWA was introduced, evaporation of CPWA water held in storage, or spills from Avalon dam, CPWA options have a reduced efficiency from the theoretical values. CPWA definitions and equations are presented below.

- Theoretical CPWA: this is either the amount of water added to the system, the amount of retired diversion, or the amount of water saved from replacement crops. Calculation methods vary depending on the CPWA option.

- Effective CPWA using corrected reoperation net depletions: this effective CPWA is computed by comparing original net depletions to CID to the net depletions computed with the CPWA option implemented. Equation 3.1 is for computing non-Project related effective CPWA with the corrected reoperation net depletion.

$$\begin{matrix}\textit{CPWA to Carlsbad} \\ \textit{Supply Using} \\ \textit{Corrected Reoperation} \\ \textit{Net Depletions}\end{matrix} = \begin{matrix}\textit{Alternative Corrected} \\ \textit{Reoperation Net Depletion} \\ \textit{to Carlsbad Supply}\end{matrix} - \begin{matrix}\textit{Alternative with} \\ \textit{CPWA Corrected} \\ \textit{Reoperation Net Depletion} \\ \textit{to Carlsbad Supply}\end{matrix} \quad \text{(Eq. 3.1)}$$

- Effective CPWA using reoperation net depletions: this effective CPWA calculation is identical to the above definition, but corrected reoperation net depletions are replaced with reoperation net depletions. Equation 3.12 is valid with this substitution of terms; only the reoperation net depletions are used instead.

- CPWA using net depletions at the CID main: also identical to the corrected reoperation definition, but net depletions at the CID main are used instead of corrected reoperation net depletions. Equation 3.12 is still valid with this substitution of terms; only the net depletion at the CID main should be used in place of the corrected reoperation net depletion.

With the exception of theoretical CPWA definition, the preceding bullets apply to computing effective CPWA for non-Project derived water. Project derived CPWA are computed by measuring the increase in available diversion amounts to the remaining farmers. The following bullets and equations describe methods used for computing daily effective CPWA for CID land retirement or leasing.

- Equations 3.2 and 3.3 calculate the respective normalized daily diversion (NDD) for the baseline and for the baseline with a retirement CPWA option.

$$NDD_{BL} = \frac{\textit{Pre-91 Daily CID Diversion}}{\textit{Original Irrigated Acreage}} \quad \text{(Eq. 3.2)}$$

$$NDD_{BL+CPWA} = \frac{\textit{Pre-91 with CPW Daily CID Diversion}}{\textit{Remaining Irrigated Acreage}} \quad \text{(Eq. 3.3)}$$

- Equations 3.4 and 3.5 compute the respective normalized daily diversions for an alternative and an alternative with a retirement CPWA option.

$$NDD_{ALT} = \frac{\textit{Alternative Daily CID Diversion}}{\textit{Original Irrigated Acreage}} \quad \text{(Eq. 3.4)}$$

$$NDD_{ALT+CPWA} = \frac{\textit{Alternative with CPWA Daily CID Diversion}}{\textit{Remaining Irrigated Acreage}} \quad \text{(Eq. 3.5)}$$

- Effective CPWA amounts are then computed by using equation 3.6 for the baseline combined with retirement CPWA or by using equation 3.7 for alternatives combined with retirement CPWA.

$$\textit{Daily Effective CPWA} = (NDD_{BL+CPWA} - NDD_{BL}) * \textit{Remaining Irrigated Acreage} \quad \text{(Eq. 3.6)}$$

$$\textit{Daily Effective CPWA} = (NDD_{ALT+CPWA} - NDD_{ALT}) * \textit{Remaining Irrigated Acreage} \quad \text{(Eq. 3.7)}$$

Cropping pattern CPWA options follow a similar format, although an additional term of cropping pattern diversions must be introduced into the equations. The following bullets and equations detail computations for determining daily effective CPWA for cropping pattern CPWA options.

- To determine normalized daily diversions for the baseline or alternative with cropping patterns as CPWA options, Equations 3.8 and 3.9 are employed. Notice that the amount diverted to the cropping pattern fields is subtracted out of the total diversion to obtain the amount of diversion to be delivered to the remaining farmers.

$$NDD_{BL+CPWA} = \frac{\textit{Pre-91 with CPWA Total CID Diversions - Crop Pattern CID Diversions}}{\textit{Total Irrigated Acreage - Crop Pattern Acreage}} \quad \text{(Eq. 3.8)}$$

$$NDD_{ALT+CPWA} = \frac{\textit{Alternative with CPWA Total CID Diversions - Crop Pattern CID Diversions}}{\textit{Total Irrigated Acreage - Crop Pattern Acreage}} \quad \text{(Eq. 3.9)}$$

- Effective CPWA amounts still use equations 3.3 and 3.5 for comparison and determination of the additional amount delivered to the remaining farmers that did not participate in the cropping pattern program. Effective CPWA amounts for cropping patterns are calculated with equations 3.10 and 3.11.

$$\textit{Daily Effective CPWA} = (NDD_{BL+CPWA} - NDD_{BL}) * (\textit{Total Irrigated Acreage} \\ \textit{- Crop Pattern Acreage}) \quad \text{(Eq. 3.10)}$$

$$\textit{Daily Effective CPWA} = (NDD_{ALT+CPWA} - NDD_{ALT}) * (\textit{Total Irrigated Acreage} \\ \textit{- Crop Pattern Acreage}) \quad \text{(Eq. 3.11)}$$

So far the entire discussion of this section is mostly concerned with effective CPWA or the portion that is used by the farmers in CID. The following sub-sections provide calculation methods for determining ineffective CPWA amounts (amounts lost in transit or to reservoir evaporation from increased detention times) and only considering efficiency to Brantley Reservoir from the CPWA option source.

3.1.3 Ineffective CPWA

Ineffective CPWA amounts include water added to or reallocated within the system that: was lost to conservation (Avalon) spills, evaporated in a reservoir, or was lost in transmission.

The portion lost to conservation spills is calculated by comparing the original net depletion to Avalon spills for a given alternative to the spill net depletion for an alternative with a CPWA option implemented. The equation for computing CPWA lost to spills (3.12) is as follows:

$$\begin{array}{l} \textit{CPWA Lost to} \\ \textit{Spills} \end{array} = \begin{array}{l} \textit{Alternative with CPWA} \\ \textit{Option Net Depletion to} \\ \textit{Carlsbad Supply due to} \\ \textit{Avalon Spills} \end{array} - \begin{array}{l} \textit{Alternative Net Depletion to} \\ \textit{Carlsbad Supply due to} \\ \textit{Avalon Spills} \end{array} \qquad \text{(Eq. 3.12)}$$

The other portion of the CPWA amount that is ineffective is due to transmission loss and evaporative loss of stored CPWA water. Equations 3.13 and 3.14 compute the respective CPWA lost in transmission and lost to evaporation.

$$\begin{array}{l} \textit{CPWA Lost in} \\ \textit{Transmission} \end{array} = \begin{array}{l} \textit{Alternative with CPWA} \\ \textit{Total Additional} \\ \textit{Transmission Losses} \end{array} - \begin{array}{l} \textit{Alternative} \\ \textit{Total Additional} \\ \textit{Transmission Losses} \end{array} \qquad \text{(Eq. 3.13)}$$

$$\begin{array}{l} \textit{CPWA Lost to} \\ \textit{Evaporation} \end{array} = \begin{array}{l} \textit{Alternative with CPWA} \\ \textit{Total Saved} \\ \textit{Reservoir Evap} \end{array} - \begin{array}{l} \textit{Alternative} \\ \textit{Total Saved} \\ \textit{Reservoir Evap} \end{array} \qquad \text{(Eq. 3.14)}$$

3.1.4 Brantley Transit Efficiency CPWA Calculations

It was decided in the EIS process that the estimated effects from CPWA options would be based upon delivering the CPWA water to Brantley reservoir, and once it is in Brantley Reservoir, it would be credited as effective CPWA. To determine the amount of effective CPWA that reached Brantley (considering only transit efficiency from the CPWA source), the (60-year average) differences in Brantley inflows and Sumner outflows were determined from the alternative-CPWA permutations compared to the original alternative (without CPWA). These calculations are depicted in equations 3.15 (for Sumner Outflow) and 3.16 (for Brantley Inflow).

$$\begin{array}{l} \textit{60-Year Average} \\ \textit{Additional Sumner} \\ \textit{Outflow} \end{array} = \begin{array}{l} \textit{Alternative with} \\ \textit{CPWA 60-Year} \\ \textit{Average Sumner} \\ \textit{Outflow} \end{array} - \begin{array}{l} \textit{Alternative} \\ \textit{60-Year Average} \\ \textit{Sumner} \\ \textit{Outflow} \end{array} \qquad \text{(Eq. 3.15)}$$

$$\begin{array}{l} \textit{60-Year Average} \\ \textit{Additional Brantley} \\ \textit{Inflow} \end{array} = \begin{array}{l} \textit{Alternative with} \\ \textit{CPWA 60-Year} \\ \textit{Average Brantley} \\ \textit{Inflow} \end{array} - \begin{array}{l} \textit{Alternative} \\ \textit{60-Year Average} \\ \textit{Brantley} \\ \textit{Inflow} \end{array} \qquad \text{(Eq. 3.16)}$$

Next, the average normalized (using Effective Brantley Storage) additional Sumner outflow is subtracted from the average additional Brantley inflow. This excludes any additional (or reduced) Sumner outflows from being included in the efficiency calculation. This becomes the amount of water realized as inflow at Brantley attributable to the water added at the CPWA source (Eq. 3.17).

$$\begin{array}{l} \textit{Inflow} \\ \textit{at Brantley due} \\ \textit{to CPWA Only} \end{array} = \begin{array}{l} \textit{60-Year Average} \\ \textit{Additional Brantley} \\ \textit{Inflow} \end{array} - 0.75 * \begin{array}{l} \textit{60-Year Average} \\ \textit{Additional Sumner} \\ \textit{Outflow} \end{array} \quad \text{(Eq. 3.17)}$$

Finally, the Brantley Transit efficiency, which is compared to either the acquired diversion amount (for FSID and River Pumper retirement) or the amount of water added or accruing to the river (for well fields and FSID gravel pit pumping), is calculated in equation 3.18.

$$\textit{Brantley Transit Efficiency} = \frac{\textit{Average CPWA at Brantley due to CPWA Only}}{\textit{Retired Diversion Amount or Amount Added to River}} \quad \text{(Eq. 3.18)}$$

In the case of retired surface water diversions, the numerator in this equation already includes the lost percentage due to only realizing the consumptive use portion of the retirement amount in the river. Pumped amounts are based on water pumped to the river and/or increased base inflows due to groundwater retirement for the well field.

3.2 Summary CPWA Results

Table 3 shows 60-year annual averages for net depletions to CID supply. Net depletions to CID supply are presented with three derivations—including and excluding spills from Avalon Dam in the long-term average and as they occur at the CID main canal (storage terms not included). Individual depletion components for corrected reoperation net depletions and reoperation net depletions, such as net depletions to Avalon spills and Effective Brantley Storage, are also presented. Table 4 shows 60-year annual averages for effective CPWA to CID supply for the most and least depletive alternatives and the Pre-91 baseline. Effective CPWA amounts computed from the two derivations are presented along with the ineffective portion of the CPWA that is lost to spills. The non-Project derived effective CPWA amounts in Table 4 are computed from the net depletion values shown in Table 3. Results in the tables are presented to the nearest ± 1 AF for ease in calculation of related parameters, but should be considered accurate only to the nearest ± 100 AF, if not ± 500 AF. Output results are presented to denote trends and for relative comparisons between alternatives; caution is advised for confidence in their absolute values.

Note that all of the permutations of CPWA options combined with alternatives are not presented in this report. Some of these model simulations were academic and were first attempts at modeling and provided guidance for subsequent improvements to later model simulations. Model simulations and results from those simulations that were not included in the output set of this report and the reasons for their omission are bulleted below.

- FSID retirement using the NMOSE's standard CIR and diversion right values: These scenarios assumed 3.0 acre-ft/acre diversion right and consisted of curbing acreages based upon that value and the diversion amount being retired (1,500 or 3,100 AF). Since FSID's diversion right divided by their irrigated acreage amounts to a per acre diversion right that is nearly 8.0 acre-ft/acre, retirement based on the 3.0 acre-ft/acre was abandoned and reduced acreages were calculated by a percentage of the reduced FSID diversion (see Section 2).

- CID retirement, retirement of “total irrigable acreage” by a constant equal to the reduction in “actual irrigated” acreage: These scenarios represented middle ground between not curbing the “total irrigable acreage” and reducing it by a ratio amount of “total irrigable acreage” to “actual irrigated acreage” (25,055 Ac / 20,000 Ac). Since reducing the entitlement by ratio and not reducing it at all produced high and low effective CPWA extremes, the middle ground values represented by reducing the “total irrigable acreage” by a constant amount were omitted from this report.

- Exact CPWA amount pumping: these scenarios used the annual net depletion values determined from the original alternative simulations to determine CPWA pumping schedules. These scenarios were deemed to be highly unrealistic since the methodology required that the net depletions to CID must be predicted before they occur. Since this method of calculating pumping schedules could never be implemented in reality, these scenarios were abandoned for the lagged CPWA pumping scenarios (see Section 2).

- Pumping scenarios with flawed second iteration base inflow sets: Earlier second iteration lagged base inflow sets did not reflect retirement of 10,000 AF/year of consumptive use in PVACD while lagged pumping was less than 10,000 AF/year. These sets did not predict the long-term base inflow gain that would be evident with such a large retirement of groundwater rights. These sets were replaced by those with the “REVRABGW” label on them. These revised sets reflect expected base inflow results for more annual consumptive use retirement than actual annual CPWA pumping.

Table 3. Net Depletions to CID Supply and Components of Net Depletions to CID Supply for Effective CPWA

Alternative and CPWA Option	Average Annual Corrected Reoperation Net Depletions to CID (AF/yr)	Average Annual Reoperation Net Depletions to CID (AF/yr)	Average Annual Net Depletions at CID Main (AF/yr)	Average Annual Net Depletions to Effective Brantley Storage (AF/yr)	Average Annual Net Depletions to Avalon Spills (AF/yr)	Average Annual Net Depletions to CID due to Avalon Spills (AF/yr)
Acme Constant (without CPWA--used for CPWA determination):	3,911	2,995	3,970	-59	-916	916
Taiban Constant (without CPWA--used for CPWA determination):	1,178	517	1,304	-126	-661	661
Pre-91(without CPWA--used for CPWA determination):	0	0	0	0	0	0
Acme Constant w/1600 AF RP Retirement:	3,097	2,408	3,176	-79	-688	688
Taiban Constant w/1600 AF RP Retirement:	623	-188	769	-145	-812	812
Pre-91 w/1600 AF RP Retirement:	-171	-524	-14	-157	-354	354
Acme Constant w/2250 AF RP Retirement:	3,224	2,223	3,308	-84	-1,000	1,000
Taiban Constant w/2250 AF RP Retirement:	595	-568	725	-130	-1,163	1,163
Pre-91 w/2250 AF RP Retirement:	129	-1,033	285	-156	-1,162	1,162
Acme Constant w/4215 AF RP Retirement:	2,374	1,488	2,482	-108	-887	887
Taiban Constant w/4215 AF RP Retirement:	-469	-1,013	-324	-144	-544	544
Pre-91 w/4215 AF RP Retirement:	-1,463	-1,417	-1,300	-163	46	-46
Acme Constant w/1500 AF FSID Retirement:	3,826	2,825	3,894	-68	-1,002	1,002
Taiban Constant w/1500 AF FSID Retirement:	610	429	740	-130	-181	181
Pre-91 w/1500 AF FSID Retirement:	-84	-127	64	-148	-42	42
Acme Constant w/3100 AF FSID Retirement:	3,513	2,658	3,582	-69	-855	855
Taiban Constant w/3100 AF FSID Retirement:	136	42	191	-54	-95	95
Pre-91 w/3100 AF FSID Retirement:	-150	-580	4	-154	-430	430

Table 3 (cont). Net Depletions to CID Supply and Components of Net Depletions to CID Supply for Effective CPWA

Alternative and CPWA Option	Average Annual Corrected Reoperation Net Depletions to CID (AF/yr)	Average Annual Reoperation Net Depletions to CID (AF/yr)	Average Annual Net Depletions at CID Main (AF/yr)	Average Annual Net Depletions to Effective Brantley Storage (AF/yr)	Average Annual Net Depletions to Avalon Spills (AF/yr)	Average Annual Net Depletions to CID due to Avalon Spills (AF/yr)
Acme Constant with Very Low Water Use CID Crop Pattern:	11,650	6,762	12,040	-389	-4,888	4,888
Taiban Constant with Very Low Water Use CID Crop Pattern:	9,539	4,420	9,982	-443	-5,119	5,119
Pre-91 with Very Low Water CID Crop Pattern:	9,965	3,495	10,340	-375	-6,470	6,470
Acme Constant with Low Water Use CID Crop Pattern:	9,747	6,053	10,063	-316	-3,694	3,694
Taiban Constant with Low Water Use CID Crop Pattern:	7,505	3,468	7,916	-410	-4,038	4,038
Pre-91 w/Low Water Use CID Crop Pattern:	7,359	2,680	7,790	-431	-4,679	4,679
Acme Constant w/Medium Water Use CID Crop Pattern:	6,989	4,486	7,226	-237	-2,503	2,503
Taiban Constant w/Medium Water Use CID Crop Pattern:	4,791	2,048	5,095	-304	-2,743	2,743
Pre-91 w/Medium Water Use CID Crop Pattern:	4,435	1,558	4,746	-311	-2,876	2,876
Acme Constant w/1500 CID acres retired (actual only):	6,183	4,801	6,367	-184	-1,382	1,382
Taiban Constant w/1500 CID acres retired (actual only):	4,601	2,101	4,833	-233	-2,500	2,500
Pre-91 w/1500 CID acres retired (actual only):	4,083	1,727	4,321	-238	-2,357	2,357
Acme Constant w/3000 CID acres retired (actual only):	9,871	6,257	10,186	-316	-3,613	3,613
Taiban Constant w/3000 CID acres retired (actual only):	8,046	3,569	8,426	-380	-4,477	4,477
Pre-91 w/3000 CID acres retired (actual only):	7,616	2,778	8,007	-391	-4,838	4,838

Table 3 (cont). Net Depletions to CID Supply and Components of Net Depletions to CID Supply for Effective CPWA

Alternative and CPWA Option	Average Annual Corrected Reoperation Net Depletions to CID (AF/yr)	Average Annual Reoperation Net Depletions to CID (AF/yr)	Average Annual Net Depletions at CID Main (AF/yr)	Average Annual Net Depletions to Effective Brantley Storage (AF/yr)	Average Annual Net Depletions to Avalon Spills (AF/yr)	Average Annual Net Depletions to CID due to Avalon Spills (AF/yr)
AC w/1500 CID acres retired (actual, and entitlement by ratio):	5,325	3,608	5,465	-140	-1,717	1,717
TC w/1500 CID acres retired (actual, and entitlement by ratio):	2,612	1,075	2,825	-213	-1,537	1,537
Pre-91 w/1500 CID acres retired (actual, and entitlement by ratio):	1,671	830	1,911	-240	-841	841
AC w/3000 CID acres retired (actual, and entitlement by ratio):	6,472	4,437	6,752	-280	-2,035	2,035
TC w/3000 CID acres retired (actual, and entitlement by ratio):	4,533	2,011	4,868	-334	-2,522	2,522
Pre-91 w/3000 CID acres retired (actual, and entitlement by ratio):	3,794	1,415	4,148	-354	-2,379	2,379
AC-Seven Rivers 10,000 AF Well Field - Lagged Pumping-I2-REV RABGW:	-1,600	-4,028	-1,351	-249	-2,428	2,428
Pre-91 with Above Pumping Series – REV RABGW:	-4,390	-7,225	-4,018	-372	-2,835	2,835
TC-Seven Rivers 10,000 AF Well Field - Lagged Pumping-I2-REV RABGW:	-1,218	-2,582	-959	-259	-1,364	1,364
Pre-91 with Above Pumping Series – REV RABGW:	-21	-1,850	-1,226	-271	-1,830	1,830
AC-Buffalo Valley 10,000 AF Well Field - Lagged Pumping-I2-REV RABGW:	-886	-2,714	-681	-205	-1,828	1,828
Pre-91 with Above Pumping Series – REV RABGW:	-3,882	-5,926	-3,548	-334	-2,044	2,044
TC-Buffalo Valley 10,000 AF Well Field - Lagged Pumping-I2-REV RABGW:	-1,292	-2,381	-1,038	-255	-1,088	1,088
Pre-91 with Above Pumping Series – REV RABGW:	-1,609	-2,963	-1,344	-265	-1,354	1,354
AC w/ Gravel Pit Pumping at 10AF/day:	3,588	2,900	3,651	-63	-688	688
TC w/ Gravel Pit Pumping at 10AF/day:	972	440	1,101	-129	-532	532
Pre-91 w/ Gravel Pit Pumping Series at 10 AF/day:	36	17	177	-141	-19	19
AC w/ Gravel Pit Pumping at 20AF/day:	3,503	2,925	3,565	-62	-579	579
TC w/ Gravel Pit Pumping at 20AF/day:	906	380	1,042	-135	-526	526
Pre-91 w/ Gravel Pit Pumping Series at 20 AF/day:	153	-85	294	-141	-238	238

Table 4. Effective CPWA to CID

Alternative and CPWA Option	Theoretical CPWA Amount Added to System (AF/yr)	Average Annual Effective CPWA using Corrected Reoperation Net Depletion to CID (AF/yr)	Average Annual Effective CPWA using Reoperation Net Depletion to CID (AF/yr)	Average Annual Effective CPWA using Net Depletion at CID Main (AF/yr)	Average Annual Effective CPWA using Normalized Daily Diversions to CID (AF/yr)	Portion of CPWA Lost to Conservation Spills (AF)
Acme Constant (without CPWA--used for CPWA determination):	0	N/A	N/A	N/A	N/A	N/A
Taiban Constant (without CPWA--used for CPWA determination):	0	N/A	N/A	N/A	N/A	N/A
Pre-91(without CPWA--used for CPWA determination):	0	N/A	N/A	N/A	N/A	N/A
Acme Constant w/1600 AF RP Retirement:	1,600	814	587	795	N/A	-227
Taiban Constant w/1600 AF RP Retirement:	1,600	555	706	535	N/A	151
Pre-91 w/1600 AF RP Retirement:	1,600	171	524	14	N/A	354
Acme Constant w/2250 AF RP Retirement:	2,250	687	772	663	N/A	85
Taiban Constant w/2250 AF RP Retirement:	2,250	584	1,085	579	N/A	502
Pre-91 w/2250 AF RP Retirement:	2,250	-129	1,033	-285	N/A	1,162
Acme Constant w/4215 AF RP Retirement:	4,215	1,537	1,508	1,489	N/A	-29
Taiban Constant w/4215 AF RP Retirement:	4,215	1,647	1,530	1,628	N/A	-117
Pre-91 w/4215 AF RP Retirement:	4,215	1,463	1,417	1,300	N/A	-46
Acme Constant w/1500 AF FSID Retirement:	1,541	85	171	76	N/A	86
Taiban Constant w/1500 AF FSID Retirement:	1,541	568	88	564	N/A	-480
Pre-91 w/1500 AF FSID Retirement:	1,541	84	127	-64	N/A	42
Acme Constant w/3100 AF FSID Retirement:	3,085	398	338	388	N/A	-60
Taiban Constant w/3100 AF FSID Retirement:	3,085	1,042	476	1,114	N/A	-566
Pre-91 w/3100 AF FSID Retirement:	3,085	150	580	-4	N/A	430

Table 4 (cont). Effective CPWA to CID

Alternative and CPWA Option	Theoretical CPWA Amount Added to System (AF/yr)	Average Annual Effective CPWA using Corrected Reoperation Net Depletion to CID (AF/yr)	Average Annual Effective CPWA using Reoperation Net Depletion to CID (AF/yr)	Average Annual Effective CPWA using Net Depletion at CID Main (AF/yr)	Average Annual Effective CPWA using Normalized Daily Diversions to CID (AF/yr)	Portion of CPWA Lost to Conservation Spills (AF)
Acme Constant w/Very Low Water Use CID Crop Pattern:	10,500	N/A	N/A	N/A	4,783	3,972
Taiban Constant w/Very Low Water Use CID Crop Pattern:	10,500	N/A	N/A	N/A	4,842	4,458
Pre-91 w/Very Low Water CID Crop Pattern:	10,500	N/A	N/A	N/A	3,505	6,470
Acme Constant w/ Low Water Use CID Crop Pattern:	8,800	N/A	N/A	N/A	3,440	2,779
Taiban Constant w/Low Water Use CID Crop Pattern:	8,800	N/A	N/A	N/A	3,577	3,377
Pre-91 w/Low Water Use CID Crop Pattern:	8,800	N/A	N/A	N/A	2,724	4,679
Acme Constant w/Medium Water Use CID Crop Pattern:	6,000	N/A	N/A	N/A	1,627	1,588
Taiban Constant w/Medium Water Use CID Crop Pattern:	6,000	N/A	N/A	N/A	1,637	2,082
Pre-91 w/Medium Water Use CID Crop Pattern:	6,000	N/A	N/A	N/A	972	2,876
Acme Constant w/1500 CID acres retired (actual only):	5,579	N/A	N/A	N/A	2,884	466
Taiban Constant w/1500 CID acres retired (actual only):	5,579	N/A	N/A	N/A	1,952	1,839
Pre-91 w/1500 CID acres retired (actual only):	5,579	N/A	N/A	N/A	1,258	2,357
	0					
Acme Constant w/3000 CID acres retired (actual only):	11,158	N/A	N/A	N/A	4,346	2,697
Taiban Constant w/3000 CID acres retired (actual only):	11,158	N/A	N/A	N/A	3,840	3,816
Pre-91 w/3000 CID acres retired (actual only):	11,158	N/A	N/A	N/A	3,151	4,838

Table 4 (cont). Effective CPWA to CID

Alternative and CPWA Option	Theoretical CPWA Amount Added to System (AF/yr)	Average Annual Effective CPWA using Corrected Reoperation Net Depletion to CID (AF/yr)	Average Annual Effective CPWA using Reoperation Net Depletion to CID (AF/yr)	Average Annual Effective CPWA using Net Depletion at CID Main (AF/yr)	Average Annual Effective CPWA using Normalized Daily Diversions to CID (AF/yr)	Portion of CPWA Lost to Conservation Spills (AF)
AC w/1500 CID acres retired (actual, and entitlement by ratio):	5,579	N/A	N/A	N/A	3,787	801
TC w/1500 CID acres retired (actual, and entitlement by ratio):	5,579	N/A	N/A	N/A	3,960	876
Pre-91 w/1500 CID acres retired (actual, and entitlement by ratio):	5,579	N/A	N/A	N/A	3,668	841
AC w/3000 CID acres retired (actual, and entitlement by ratio):	11,158	N/A	N/A	N/A	7,781	1,119
TC w/3000 CID acres retired (actual, and entitlement by ratio):	11,158	N/A	N/A	N/A	7,398	1,861
Pre-91 w/3000 CID acres retired (actual, and entitlement by ratio):	11,158	N/A	N/A	N/A	7,010	2,379
AC-Seven Rivers 10,000 AF Well Field - Lagged Pumping-I2-REV RABGW:	10,000	5,511	7,023	5,322	N/A	1,512
Pre-91 with Above Pumping Series - REV RABGW:	10,000	4,390	7,225	4,018	N/A	2,835
TC-Seven Rivers 10,000 AF Well Field - Lagged Pumping-I2-REV RABGW:	10,000	2,396	3,099	2,263	N/A	703
Pre-91 with Above Pumping Series - REV RABGW:	10,000	21	1,850	1,226	N/A	1,830
AC-Buffalo Valley 10,000 AF Well Field - Lagged Pumping-I2-REV RABGW:	10,000	4,797	5,709	4,651	N/A	912
Pre-91 with Above Pumping Series - REV RABGW:	10,000	3,882	5,926	3,548	N/A	2,044
TC-Buffalo Valley 10,000 AF Well Field - Lagged Pumping-I2-REV RABGW:	10,000	2,471	2,898	2,342	N/A	428
Pre-91 with Above Pumping Series - REV RABGW:	10,000	1,609	2,963	1,344	N/A	1,354
AC w/ Gravel Pit Pumping at 10AF/day:	222	323	96	319	N/A	-228
TC w/ Gravel Pit Pumping at 10AF/day:	249	206	77	203	N/A	-129
Pre-91 w/ Gravel Pit Pumping Series at 10 AF/day:	248	-36	-17	-177	N/A	19
AC w/ Gravel Pit Pumping at 20AF/day:	288	408	70	405	N/A	-337
TC w/ Gravel Pit Pumping at 20AF/day:	296	272	137	262	N/A	-135
Pre-91 w/ Gravel Pit Pumping Series at 20 AF/day:	291	-153	85	-294	N/A	238

3.3 Detailed CPWA Results

The following sub-sections present effective CPWA amounts on a daily and cumulative daily basis. Detailed CPWA results are provided to show the relation that timing of CPWA has on the effective CPWA amount. In addition to example daily effective CPWA figures and cumulative daily effective CPWA figures, the last sub-section reconciles ineffective and effective CPWA amounts for Project derived CPWA options.

3.3.1 Brantley Transit Efficiencies for Non-Project CPWA Options

Brantley transit efficiencies for non-Project CPWA options are presented in Table 5. These efficiencies only consider the transit loss from the CPWA source to Brantley Reservoir. Efficiencies for retired diversions consider the retired diversion amount. Efficiencies for pumping include both the pumped amounts and any base inflow gain due to retirement. It should be noted that efficiencies for well field options don't consider the retired groundwater consumptive use that made the base inflow change possible. These numbers were presented in the EIS and for the respective top to bottom listings in the well field section of Table 5 would be: 92%, 76%, 42%, and 40%. They represent transit efficiency to Brantley including effects such as evapotranspiration from the Roswell basin aquifer and the effects of reduced irrigation return flows caused by the retired groundwater diversion. These efficiencies can be calculated by dividing the values in the fourth column for the well field by 10,000 acre-feet.

Table 5. Transit Efficiencies to Brantley from the CPWA Source for Non-Project CPWA Options (all values except efficiency are 60-year averages in acre-feet per year)

Option / Permutation	Additional Sumner Outflow [1]	Additional Brantley Inflow	Inflow at Brantley due to CPWA Only	Retired Diversion or Total Inflows to River	Brantley Transit Efficiency
Acme Constant with 1500 AF from FSID	-69	182	251	1500	17%
Acme Constant with 3000 AF from FSID	-113	354	467	3000	16%
Taiban Constant with 1500 AF from FSID	-250	203	453	1500	30%
Taiban Constant with 3000 AF from FSID	-424	465	889	3000	30%
Average FSID CPWA - Brantley Transit Efficiency					23%
Acme Constant with 1600 AF from River Pumpers	-228	600	828	1600	52%
Acme Constant with 2250AF from River Pumpers	-218	899	1116	2250	50%
Acme Constant with 4215 AF from River Pumpers	-318	1922	2240	4215	53%
Taiban Constant with 1600 AF from River Pumpers	-79	872	951	1600	59%
Taiban Constant with 2250 AF from River Pumpers	-102	1264	1366	2250	61%
Taiban Constant with 4215 AF from River Pumpers	-373	1893	2266	4215	54%
Average River Pumper CPWA - Brantley Transit Efficiency					55%
Acme Constant with Seven Rivers Wellfield	-1334	7818	9153	9961	92%
Acme Constant with Buffalo Valley Wellfield	-1291	6262	7553	8846	85%
Taiban Constant with Seven Rivers Wellfield	-701	3502	4203	4618	91%
Taiban Constant with Buffalo Valley Wellfield	-645	3343	3988	4462	89%
Average Wellfield - Brantley Transit Efficiency					82%
Acme Constant with Gravel Pit Pumping at 10AF/day[2]	-56	102	158	222	71%
Acme Constant with Gravel Pit Pumping at 20AF/day[2]	-92	106	198	288	69%
Taiban Constant with Gravel Pit Pumping at 10AF/day[2]	-19	159	178	249	72%
Taiban Constant with Gravel Pit Pumping at 20AF/day[2]	-32	214	246	296	83%
Average Gravel Pit Pumping – Brantley Transit Efficiency					75%

[1]Additional Sumner Outflow in this column is normalized by 75%.
[2]Maximum annual pumping rate of 300 acre-feet per year.

3.3.2 Non-Project Derived—Daily Effective CPWA

Daily effective CPWA amounts and depletions for non-Project derived CPWA options are computed identically to those annual values presented in Tables 3 & 4 and equations 3.1 through 3.12, with the exception that annual values are replaced with daily values. Examining daily depletion and effective CPWA amounts helps to describe CPWA effectiveness, especially considering timing. CPWA options are most effective if they are delivered as the depletion is occurring (if it is within the irrigation season) or if it is delivered before it will be missed by the diverter (if the depletion occurs in the non-irrigation season). Figures 1-4 show daily net depletion and effective CPWA example years for the four non-CID retirement options coupled with the Acme Constant alternative. Net depletions and effective CPWA amounts at the CID main are presented to remove the large day-to-day swings evident as water moves into and out of the channel when using the daily corrected reoperation net depletion. In the case of Figures 1-4, all of the CPWA options show some effectiveness; however, some years in the modeling show the CPWA option is not making any difference in the net depletion at the CID main, and in some years the poor timing of an option with bad storage configurations can actually increase the net depletion. Figure 5 is an example of the latter problem occurring in a select year.

Explanation and observations concerning the following figures are bulleted below:

- Figure 1 shows net depletions at the CID main for Acme Constant based on 1951 hydrologic conditions, with and without 2,250 AF/year of river pumper diversions retired. The blue line denotes the net depletion caused by reoperation aspects of the alternative alone. The orange line represents the net depletion after the CPWA is applied. It is evident from the figure that the depletion was eliminated completely from March 1, 1951 to September 1, 1951 (the orange line indicates zero depletion with CPWA). From September 1, 1951, to the end of the irrigation season, the CPWA did not reduce the net depletion completely, but did reduce the net depletion by approximately 5-10 acre-ft/day.

- Figure 2 illustrates net depletions at the CID main for Acme Constant based on 1949 hydrologic conditions, with and without 3,100 AF/year of forbearance from FSID. Note that CPWA is effective for almost the entire irrigation season with the exceptions of where the blue line (alternative depletion only) dips below the orange line (alternative depletion with CPWA) in the spring and in the summer.

- Net depletions at the CID main, for Acme Constant for 1989 hydrologic conditions, are shown in Figure 3, with and without CPWA pumping and 10,000 AF/year of groundwater right retirement in PVACD. The square saw tooth green line represents lagged CPWA pumping. Note that from March to September the orange line (alternative with CPWA) actually delivers more water to CID than the Pre-91 model did (negative net depletion at the CID main). For the remainder of the year past September, the pumping and increased base inflows eliminate the depletions completely, but with no additional delivery (net depletion with CPWA is zero).

- Figure 4 shows a year (1991 hydrologic conditions) where not much depletion was evident at the CID main for Taiban Constant. Looking at the difference between the orange line (alternative with CPWA) and the blue line (alternative alone) shows an effective CPWA amount near 15 AF/day due to FSID gravel pit pumping. Comparing total areas under the green line to the area in between the orange and blue lines, it is apparent from the figure that the CPWA volume pumped was not nearly as large as the effective CPWA volume (creating efficiency at the CID main greater than 100%). This extra pumping helped to push the allotment higher (note the date is 7/15), and caused realization of CPWA much larger than what was actually added to the system.

- Converse to the previous bullet, Figure 5 illustrates that in some cases CPWA water can be added to the system causing the net depletions to become higher. For the modeled year of 1952 with Acme Constant, the orange line shows an additional net depletion larger than the original net depletion. This signifies that the CPWA water worsened the net depletions. This example occurs in some years with nearly every type of CPWA option although FSID supplies are directly tied back to bypass volumes since return flows diminish with FSID forbearance. This indicates that the root cause of the increased net depletion is a product of timing and storage configurations causing the allotment with the CPWA water applied to be set lower than it was without the addition of CPWA water. This occurs fairly rarely in the CPWA model output, but is still worth noting.

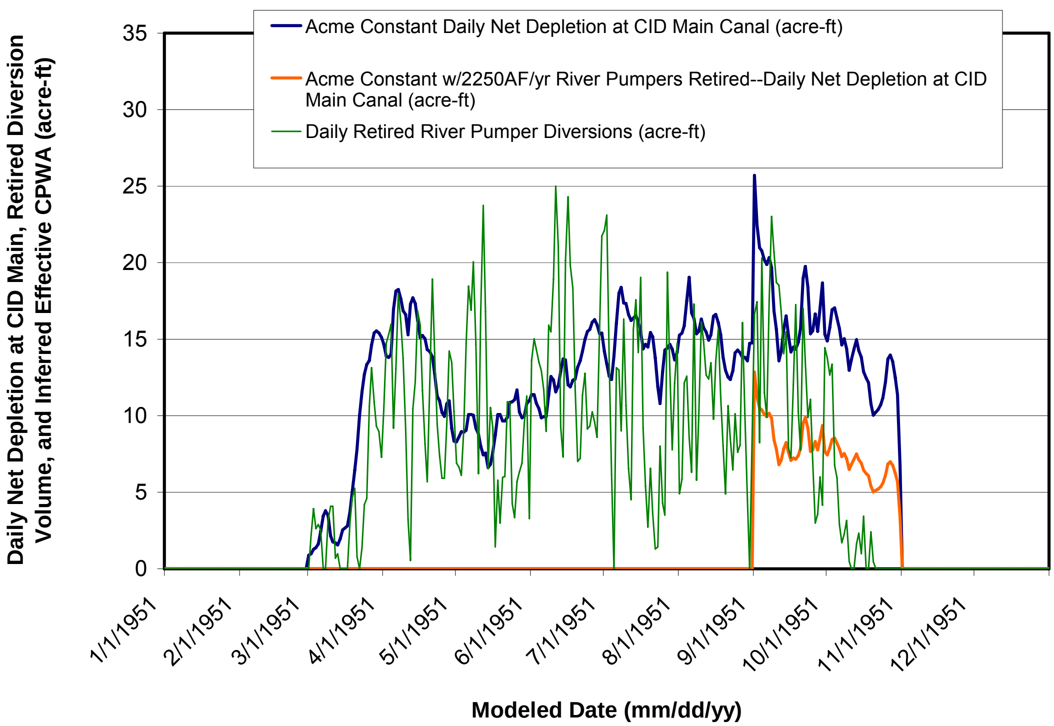

Figure 1. Acme Constant with 2,250 AF/year of River Pumper Retirement—Daily Net Depletions, Retired River Pumper Diversions, and Inferred Effective CPWA (See bulleted text in Section 3.3.2 for Figure explanation).

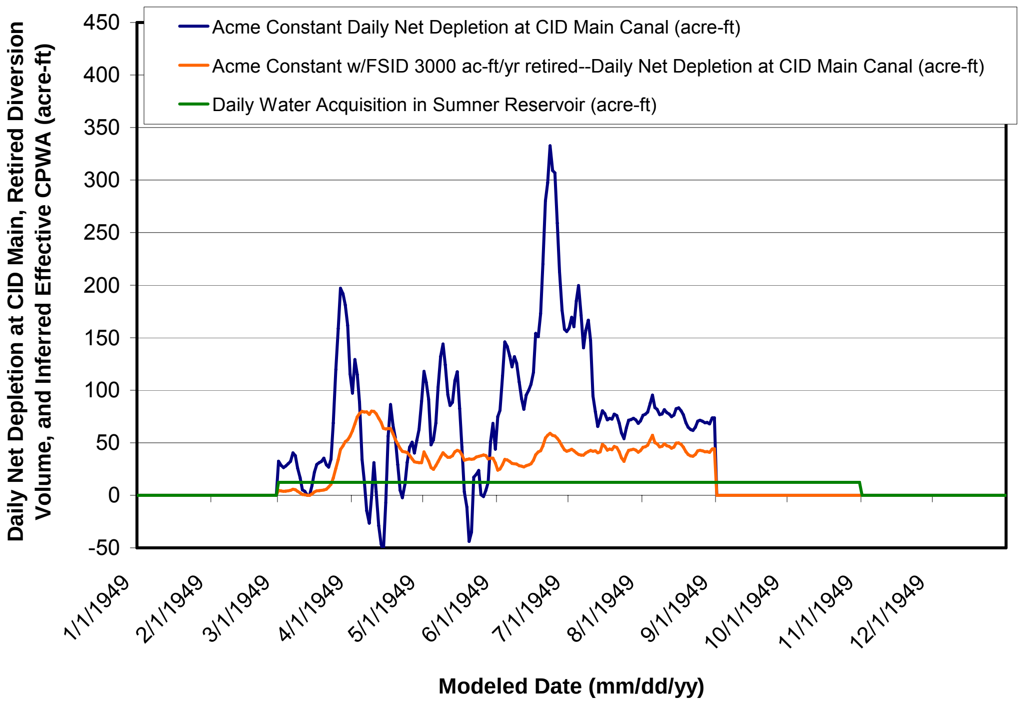

Figure 2. Acme Constant with 3,100 AF/year of FSID Retirement—Daily Net Depletions, Retired FSID Diversions, and Inferred Effective CPWA (See text in Section 3.3.2 for explanation).

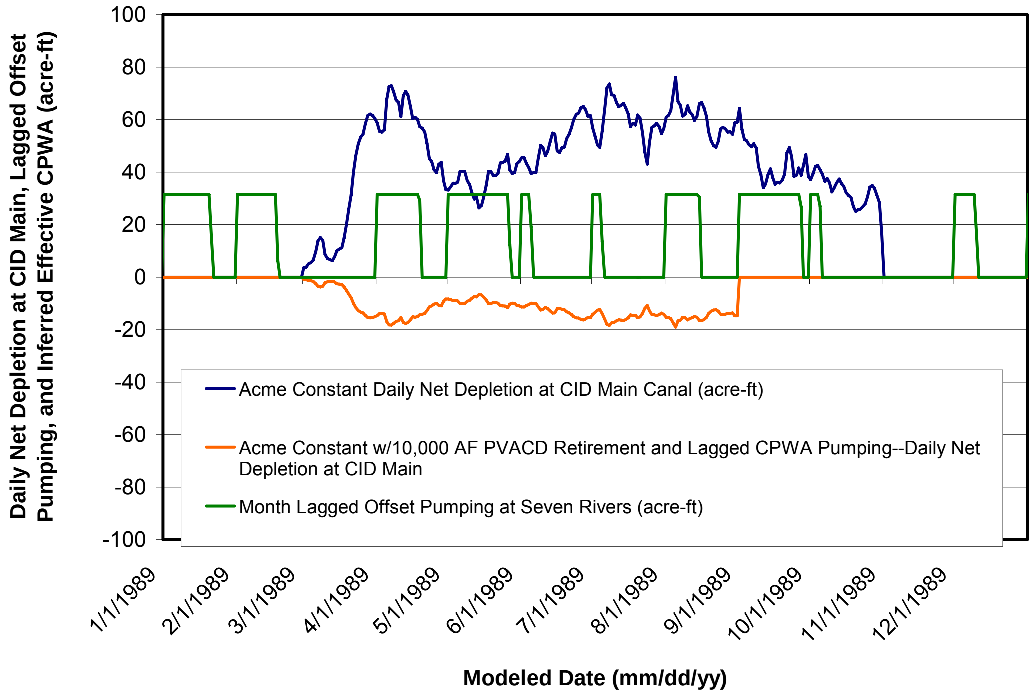

Figure 3. Acme Constant with 10,000 AF/year of PVACD Retirement and Month Lagged Well field Pumping—Daily Net Depletions, CPWA Pumping, and Inferred Effective CPWA (See text in Section 3.3.2 for explanation).

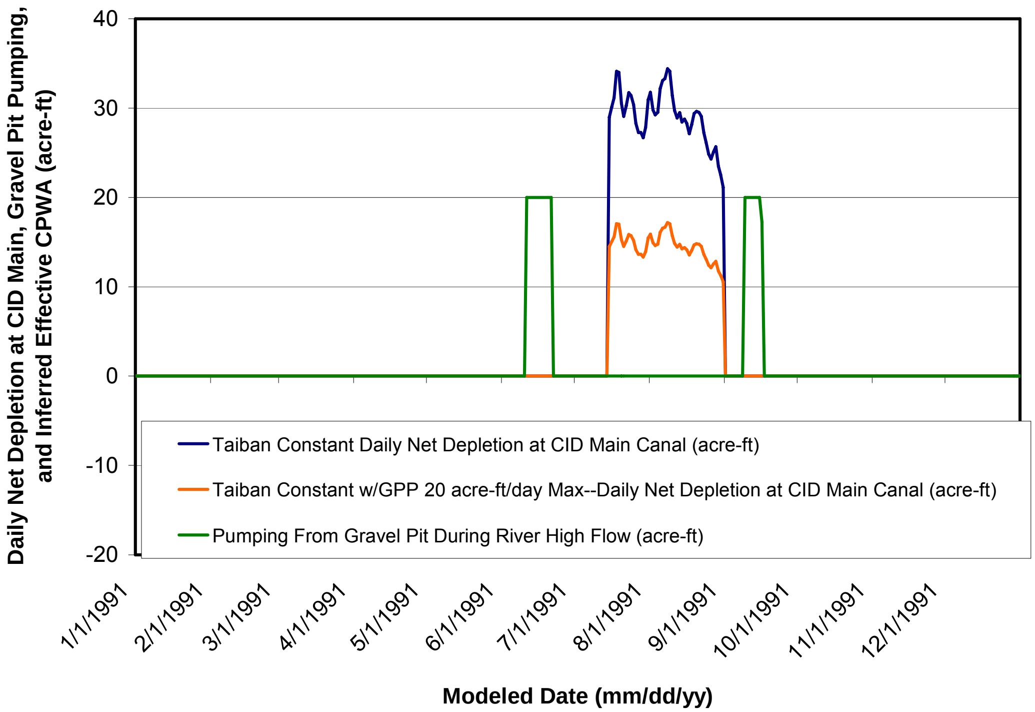

Figure 4. Taiban Constant with 20 AF/day Max. Gravel Pit Pumping—Daily Net Depletions, Gravel Pit Pumping, and Inferred Effective CPWA (See text in Section 3.3.2 for explanation).

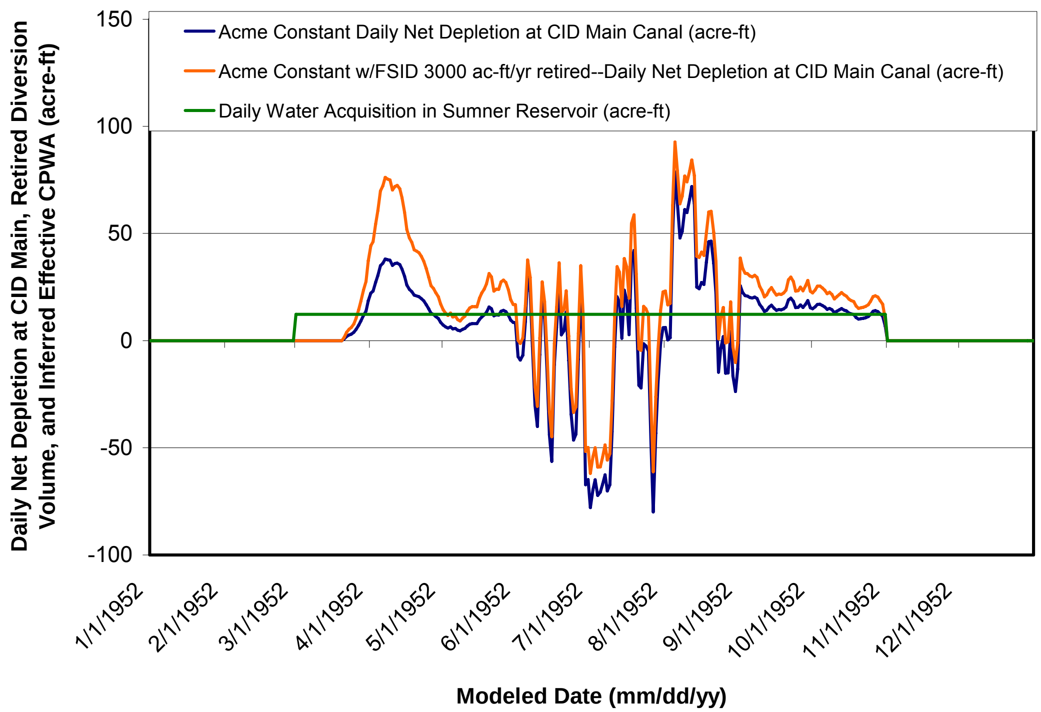

Figure 5. Acme Constant with 3,100 AF/Yr of FSID Retirement—Daily Net Depletions, Retired FSID Diversions, and Inferred (Ineffective) CPWA (See text in Section 3.3.2 for explanation).

3.3.3 Non-Project Derived—Cumulative 60-year Effective CPWA

Example cumulative 60-year corrected reoperation net depletions with and without non-Project CPWA options are presented in this section. The cumulative corrected reoperation net depletion shows large day-to-day swings, which are a result of how the depletions are computed. As stated in the previous section, these large swings are caused by water moving into and out of the channel, mostly flood flows and block releases, in both the action and baseline model simulations. Since the volume of water in the river channel is unaccounted for in the net depletion computations, this water shows up as a net depletion for a period until the volume makes it to the next reservoir in the action or baseline model. Figures 4-6 illustrate the variations in the effectiveness of the CPWA option due to changing hydrologic conditions, but they also capture the long term trend over time for a particular CPWA option.

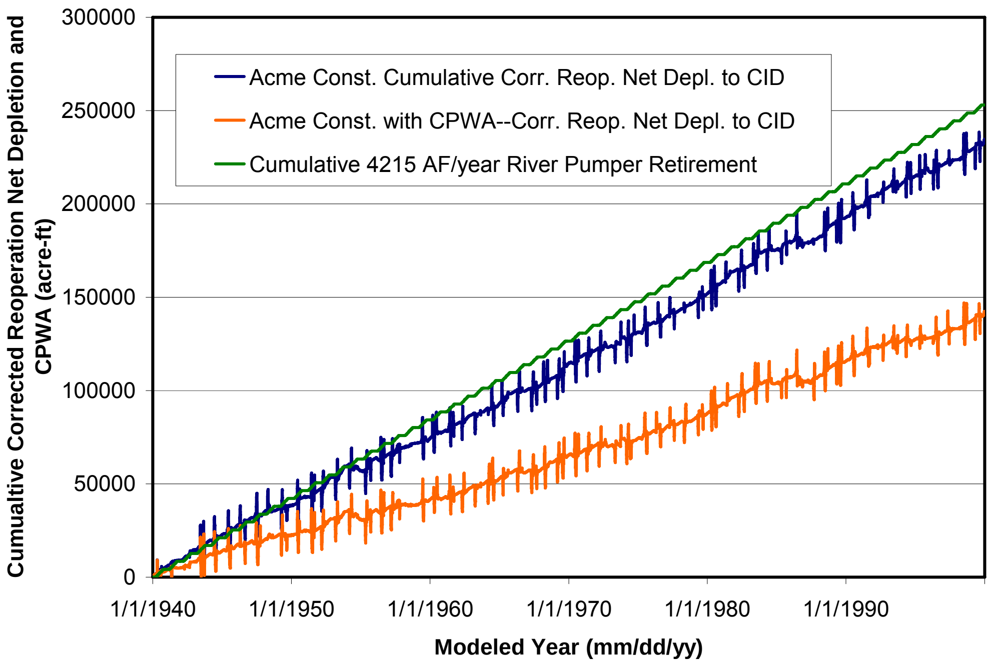

Figure 6. Acme Constant with 4215 AF/year of River Pumper Retirement—Cumulative Daily Net Depletions and Cumulative Retired River Pumpers

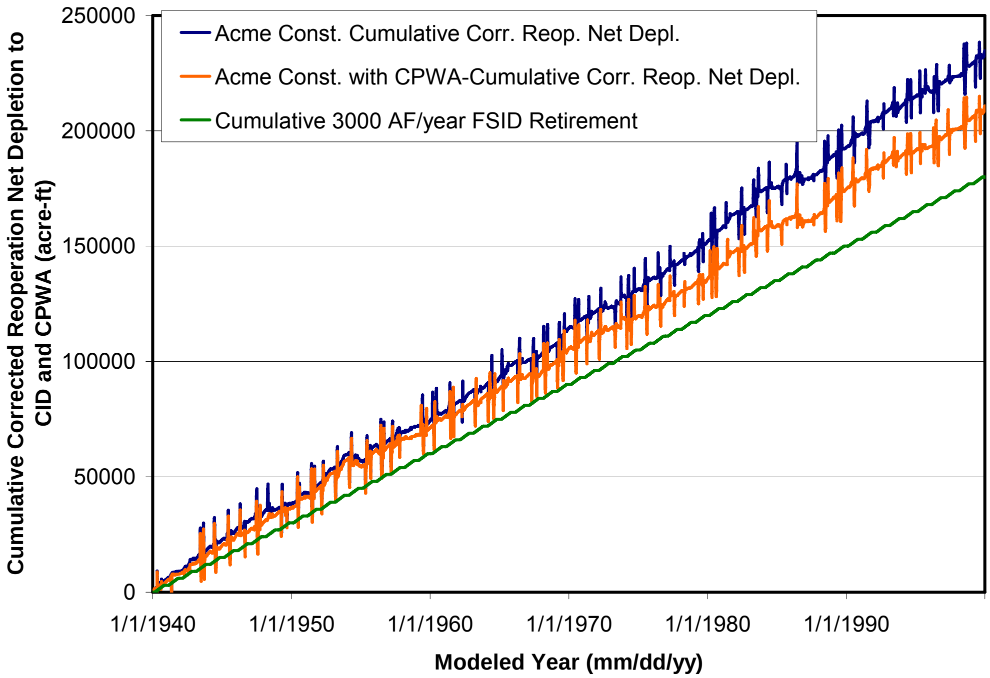

Figure 7. Acme Constant with 3,100 AF/year of FSID Retirement—Cumulative Daily Net Depletions and Cumulative FSID Retirement Volume

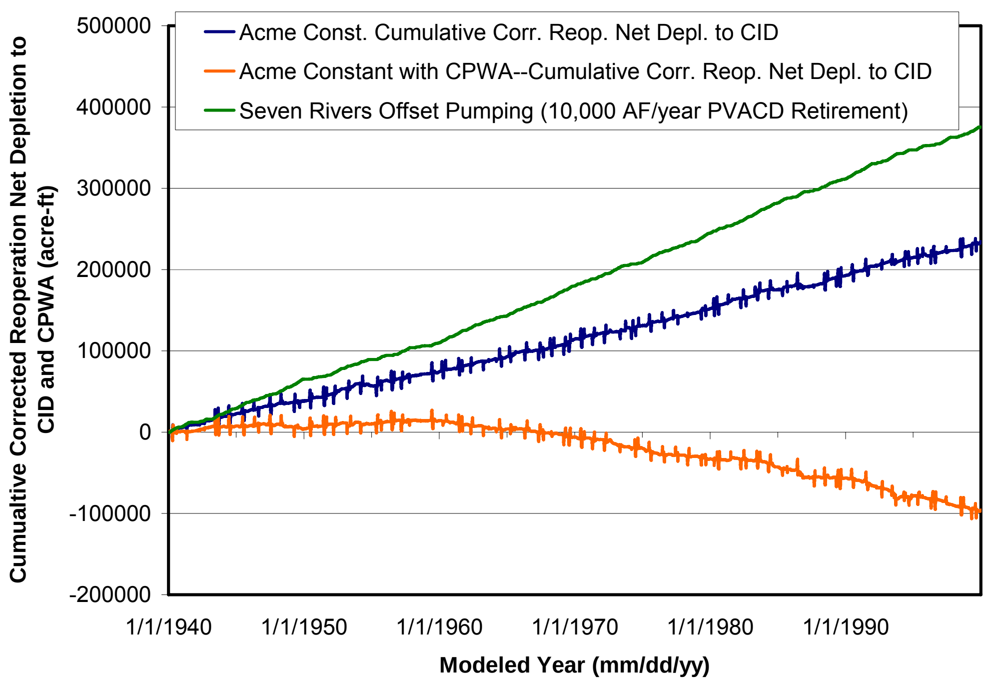

Figure 8. Acme Constant with 10,000 AF/year of PVACD Retirement and Seven Rivers Lagged Month Well Field Pumping—Cumulative Daily Net Depletions and Cumulative Pumping

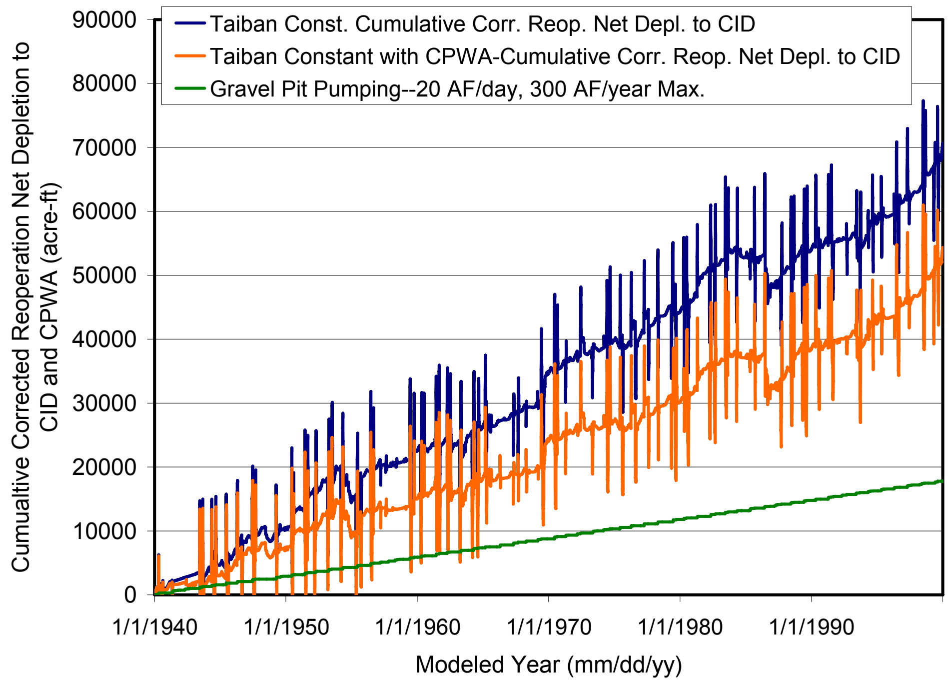

Figure 9. Taiban Constant with 300 AF/year Maximum, 20 AF/day with a 350 cfs River Flow Delivery Trigger—Cumulative Daily Net Depletions and Cumulative Pumping

3.3.4 Daily Effective CPWA Utilizing Project Supply

CPWA options that utilize Carlsbad Supply must be handled separately. Although retirement in CID represents a reduction of demand, it also creates larger net depletions to CID by the definition of net depletions. Straight retirement of CID acreage without subsequent planning policy to deliver retired CPWA water produces model results showing both increased additional depletions in the form of Avalon spills and evaporation. These losses would likely be available to balance out net depletions to the remaining farmers caused by reoperations for the PBNS, but only if it is delivered in greater quantity to augment their existing supply. In years where these remaining farmers were apportioned a full allotment, they cannot be eliminated since their (farm delivery) allotment is capped at 3.7 acre-ft/acre.

Calculation of daily effective CPWA amounts to the remaining farmers is accomplished by using equations 3.2 through 3.11. Figure 10 illustrates daily realized effective CPWA for the remaining farmers in the modeled year 1956 with the Acme Constant alternative and a 3,000 “actual irrigated acreage” reduction. Figure 11 illustrates daily realized effective CPWA for the remaining farmers also in the modeled year of 1956 with the Acme Constant alternative, a 3,000 “actual irrigated acre” reduction (acreage used to determine diversions), and a reduction in “total irrigable acreage” (acreage used to determine allotment per acre) by ratio, which amounted to 3,800 acres. As explained in the assumptions section, the reduction in “total irrigable acreage” simulates additional policy for spreading the water over a smaller portion of farm land, more effectively redistributing the water that becomes available from the retired CID farms. Comparing figures 10 and 11, it is evident that the saved diversion pattern is the same, but the daily effective CPWA magnitudes, for the scenario that also uses the irrigable acreage reduction by ratio in the model, are greater. Figure 12 again presents the same year for comparison, but this permutation is the Acme Constant alternative with 5,000 irrigated acres in the cropping pattern program with diversions limited to a low water use crop (~1.2 acre-ft/acre at the farm headgate). Comparing with the preceding figures, once again it is evident that the same pattern of diversion savings is realized except the daily effective CPWA magnitudes are lower than those shown for the retirement scenarios.

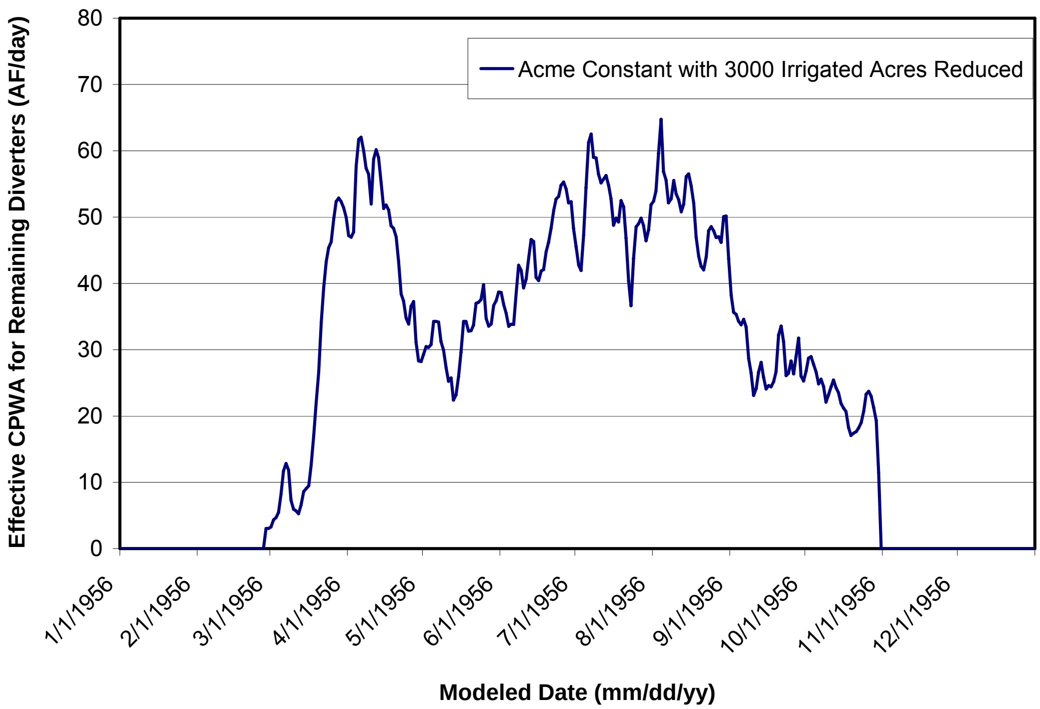

Figure 10. Effective CPWA for the Remaining Farmers (17,000 acres) within the CID for the Acme Constant Alternative with 3,000 Actual Irrigated Acres Retired.

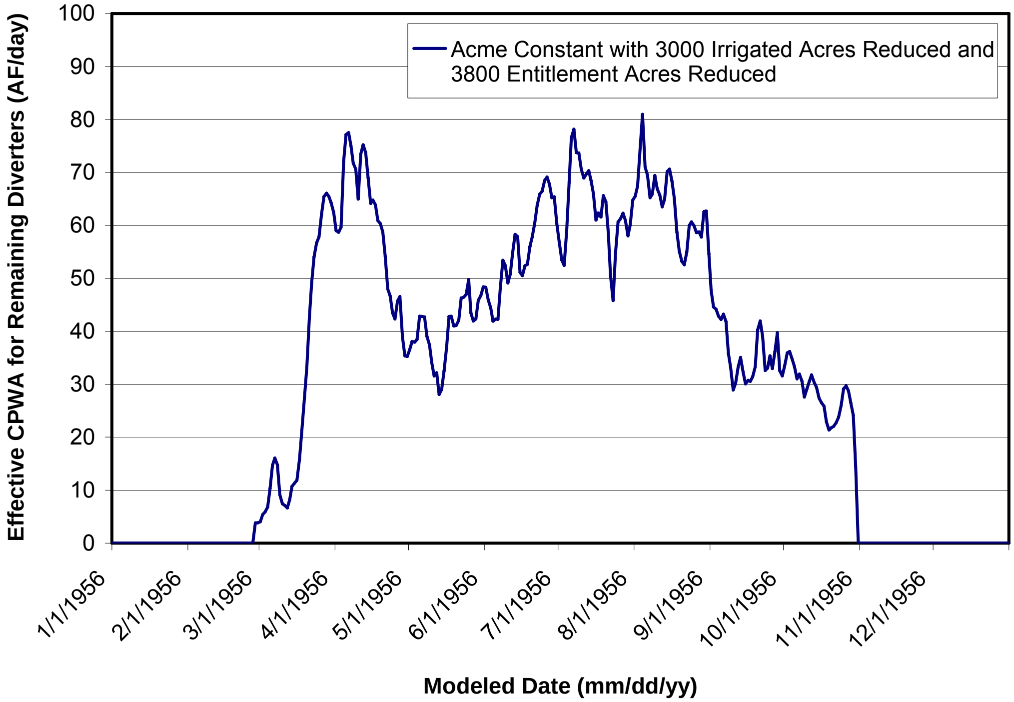

Figure 11. Effective CPWA for the Remaining Farmers (17,000 acres) within the CID for the Acme Constant Alternative with 3,000 Actual Irrigated Acres Retired and 3,800 Irrigable Acres Reduced.

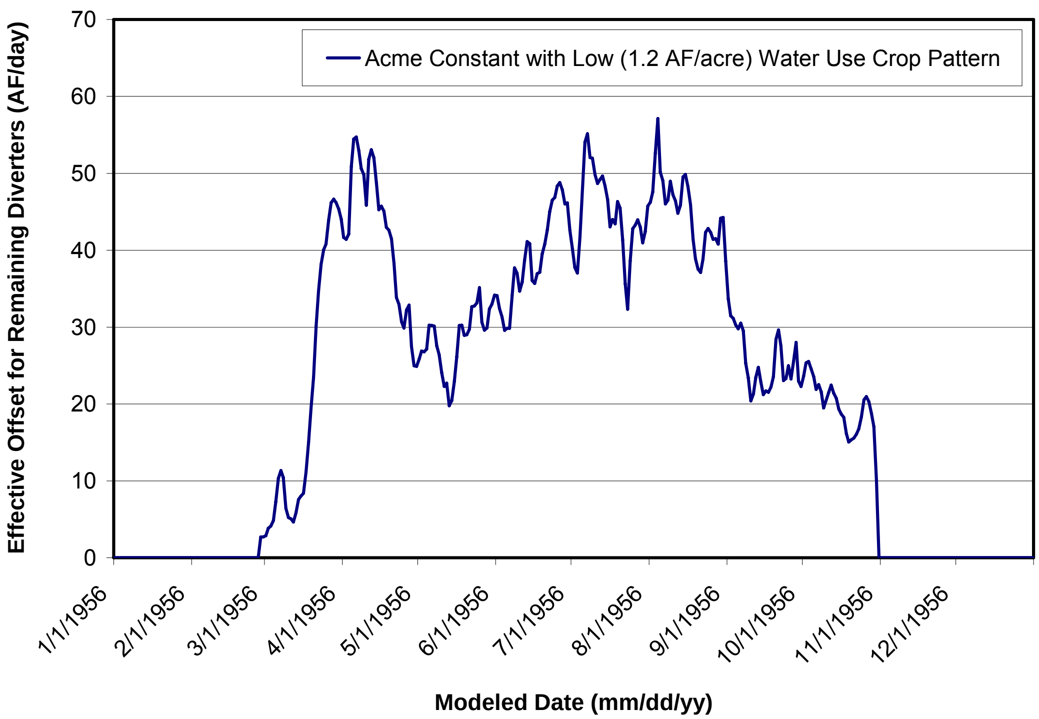

Figure 12. Effective CPWA for Farmers not Participating in the Cropping Pattern Program (15,000 acres) within the CID for the Acme Constant Alternative with 5,000 Irrigated Acres Limited to Farm Deliveries of 1.2 acre-ft/acre.

3.3.5 Cumulative 60-year Effective CPWA Amounts Utilizing Carlsbad Supply

Example cumulative 60-year daily effective CPWA amounts for Project derived CPWA options are presented in this section. Figure 13 presents the same three alternative/CPWA permutations presented in the previous section compared with a 60-year cumulative graph. The same trend of effective CPWA can be noted in this figure, which shows that the retirement with policy changes (simulated by “total irrigable acreage” reduction by ratio) delivers the most effective CPWA amounts. The straight irrigated acreage reduction (with no policy changes and no reduction in the “total irrigable acreage” used to compute allotments per acre) is second most in quantity of effective CPWA. The cropping pattern option delivers the smallest amount of effective CPWA. It is interesting to note from the figure that some of the flat slopes on the individual lines correspond to times when CID farmers had a nearly full allotment. In these times, unless the maximum allotment is increased, the CPWA option is totally ineffective and some of the water that becomes available is lost to evaporation in reservoirs or spills since it cannot be used at that time. This is most evident in the early 40’s and the late 80’s and early 90’s when the incoming water supply was fairly large. Policy changes do help to make some of that water available to other farmers as the increased slopes for the entitlement reduction alternative/option combination shows, but flat spots still exist demonstrating that a maximum diversion per acre ceiling is still reached in some years.

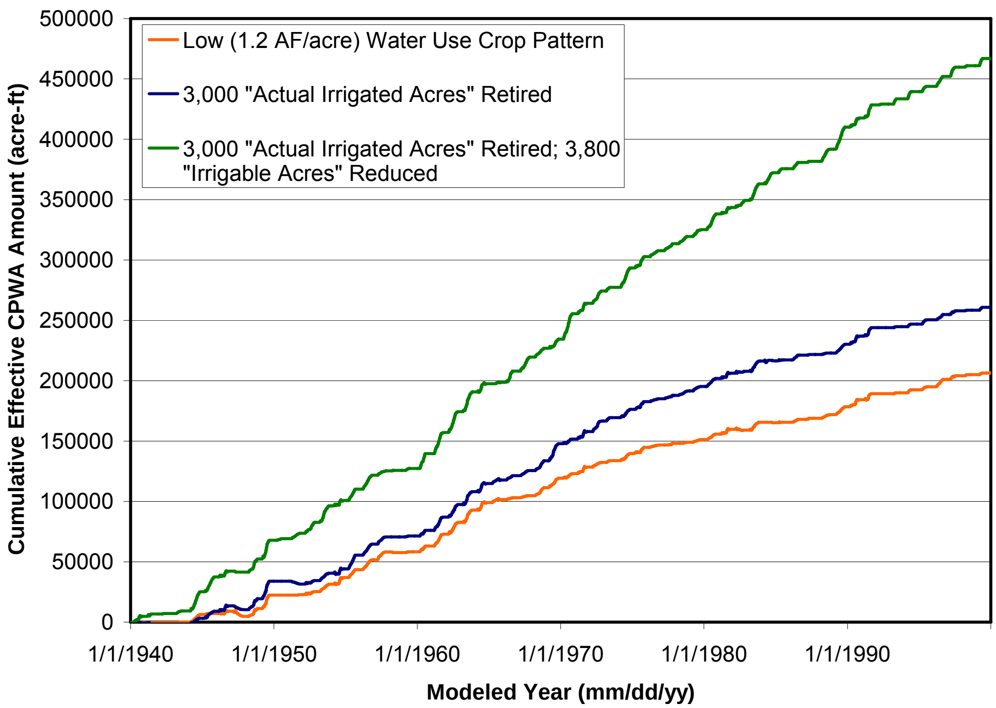

Figure 13. Cumulative Effective CPWA for 3,000 acre (Actual and by Ratio) Retirement CPWA Options Shown with 5,000 acre Cropping Pattern Change to Farm Deliveries Limited to 1.2 acre-ft/acre.

3.3.6 Ineffective and Effective CPWA Mass Balance

To determine how the reapportioned water within CID's supply is consumed as ineffective CPWA, the equations in Briggs et al (2005) were employed. Table 6 shows additional transmission depletions and saved evaporation compared to the Pre-91 condition for the original proposed alternatives (without CPWA). Table 7 presents the same net depletion components (compared with Pre-91) for the CID CPWA options listed previously in this memorandum. Table 8 presents average annual ineffective CPWA amount normalized using Effective Brantley Storage with equations 3.12 through 3.14 and normalized effective CPWA using equations 3.2 through 3.11. Comparing the sum of the ineffective and effective portions with the original theoretical CPWA amount (Table 4) shows that the CID retirement CPWA options reconcile quite well with theoretical CPWA amounts, but some discrepancy is still noted. Reasons for the slight discrepancy include allotment differences between the pre-91 model and the given alternative/retirement permutation along with normalizing the upstream depleted water with Effective Brantley Storage. The cropping pattern options don't reconcile as well between the theoretical value and the sum of the effective and ineffective CPWA components. Examining differences in total diversions indicates that much less water is being diverted for the cropping pattern options than for the CID retirement options. Since no policy changes were implemented, like estimating the savings and adding that amount back into the algorithm that determines the allotment, a larger volume of water is detained in the reservoirs than with any of the retirement options. This increases the reservoir evaporative losses for these options, and subsequently increases the mass balance discrepancy since upstream ineffective CPWA (as evaporation) is normalized with Effective Brantley Storage. With proper policy for these cropping pattern options, a significant portion of evaporated and spilled water would be available to redistribute to remaining farmers; however, a portion of the spilled water due to modified operations would not be recovered.

Table 6. Additional Transmission Loss and Saved Evaporation Measured as Effective Brantley Storage with Net Depletions due to Spills at Avalon Dam—Original Alternatives (without CPWA).

Alternative	Average Additional Transmission Loss Measured as Effective Brantley Storage (acre-ft/year)	Average Saved Evaporation Measured as Effective Brantley Storage (acre-ft/year)	Average Additional Net Depletion due to Spills from Avalon Dam (acre-ft/year)
Acme Constant	4378	1401	916
Acme Variable	3251	958	723
Critical Habitat	1074	393	577
Taiban Constant	986	447	661
Taiban Variable LRS	1183	371	400
Taiban Variable MRS	1811	595	323
Taiban Variable HRS	2509	601	-209
No Action w/6-wk	2238	725	883
No Action wo/6-wk	2248	687	-13

Table 7. Additional Transmission Loss and Saved Evaporation Measured as Effective Brantley Storage with Net Depletions due to Spills at Avalon Dam—CID CPWA Options with Taiban and Acme Constant Alternatives.

Alternative with CPWA Option	Average Additional Transmission Loss Measured as Effective Brantley Storage (acre-ft/year)	Average Saved Evaporation Measured as Effective Brantley Storage (acre-ft/year)	Average Additional Net Depletion due to Spills from Avalon Dam (acre-ft/year)
AC w/1500 Ac. CID Actual Ret.	4601	-103	1382
AC w/3000 Ac. CID Actual Ret.	4656	-1397	3613
TC w/1500 Ac. CID Actual Ret.	1208	-807	2500
TC w/3000 Ac. CID Actual Ret.	1206	-2175	4477
AC w/1500 Ac. CID Ratio Ret.	4546	1006	1717
AC w/3000 Ac. CID Ratio Ret.	4577	267	2035
TC w/1500 Ac. CID Ratio Ret.	1057	16	1537
TC w/3000 Ac. CID Ratio Ret.	1332	-572	2522
AC w/ L-1 (Average)	4663	-1387	3360
AC w/L-2 (Cotton)	4728	-1123	3695
AC w/L-3 (Small Grain)	4810	-1694	4888
AC w/L-4 (Corn)	4503	153	2503
TC w/L-1 (Average)	1307	-2128	3996
TC w/L-2 (Cotton)	1294	-1995	4038
TC w/L-3 (Small Grain)	1360	-2830	5119
TC w/L-4 (Corn)	1233	-716	2743

Table 8. Average Annual Effective and Ineffective CPWA Amounts for CID Retirement and Cropping Pattern Options.

Alternative w/ CPWA Option	Average Additional Transmission Loss as Compared to Original Alternative (normalized to BES - acre-ft/year)	Average Additional Evaporation as Compared to Original Alternative (normalized to BES - acre-ft/year)	Average Additional Spill as Compared to Original Alternative (acre-ft/year)	Total Ineffective CPWA Amount Including Spilled Water (normalized to BES - acre-ft/year)	Effective CPWA Amount (already applied through increased allotments--acre-ft/year)	Sum of Ineffective and Effective CPWA Amounts (acre-ft/year)
AC w/1500 acres actual*	224	1504	466	2194	2884	5079
AC w/3000 acres actual*	279	2798	2697	5774	4346	10121
TC w/1500 acres actual*	222	1254	1839	3315	1952	5267
TC w/3000 acres actual*	219	2622	3816	6658	3840	10498
AC w/1500 acres ratio**	169	395	801	1365	3787	5152
AC w/3000 acres ratio**	200	1135	1119	2453	7781	10234
TC w/1500 acres ratio**	71	431	876	1378	3960	5338
TC w/3000 acres ratio**	345	1019	1861	3225	7398	10624
AC w/ L-1	286	2788	2444	5518	3813	9331
AC w/L-2	350	2524	2779	5653	3440	9094
AC w/L-3	433	3095	3972	7501	4783	12284
AC w/L-4	125	1249	1588	2962	1627	4589
TC w/L-1	321	1834	3335	5490	3762	9252
TC w/L-2	308	1570	3377	5255	3577	8832
TC w/L-3	373	2141	4458	6972	4842	11814
TC w/L-4	246	295	2082	2624	1637	4261

* Even though changed policy was not implemented, a portion of the reduced diversion goes to redistribute retired water to remaining farmers since the allotment computation is based on available water in storage; however, the portion that evaporates in between the allotment allocation dates and when the reduced diversion accumulates is lost.
** Ratio retirement was implemented to demonstrate policy to enhance redistribution of retired water to the remaining farmers; redistribution for remaining farmers could also be implemented by estimating future saved diversion amounts and applying them to the allotment computation.

3.3.7 Relation between Ineffective CPWA from Spills and Added Theoretical CPWA Volumes

Some CPWA options, such as Project derived options, exhibit an increasing conservation spill trend with water added to or reallocated within the Pecos River System. Figure 14 correlates CPWA lost to spills with theoretical CPWA amounts added to or reallocated within the Pecos River System. All of the CPWA results presented in this report are included in the figure. It is apparent from the figure that as added/reallocated water volumes increase, an increased portion of that CPWA option is lost to conservation spills. Figure 14 also demonstrates the linear dependence exhibited by all the CPWA options considering either the alternative or baseline the CPWA option was combined with, policy differences between the administration of CPWA volumes, or differing pumping series for the same amount of retirement within PVACD.

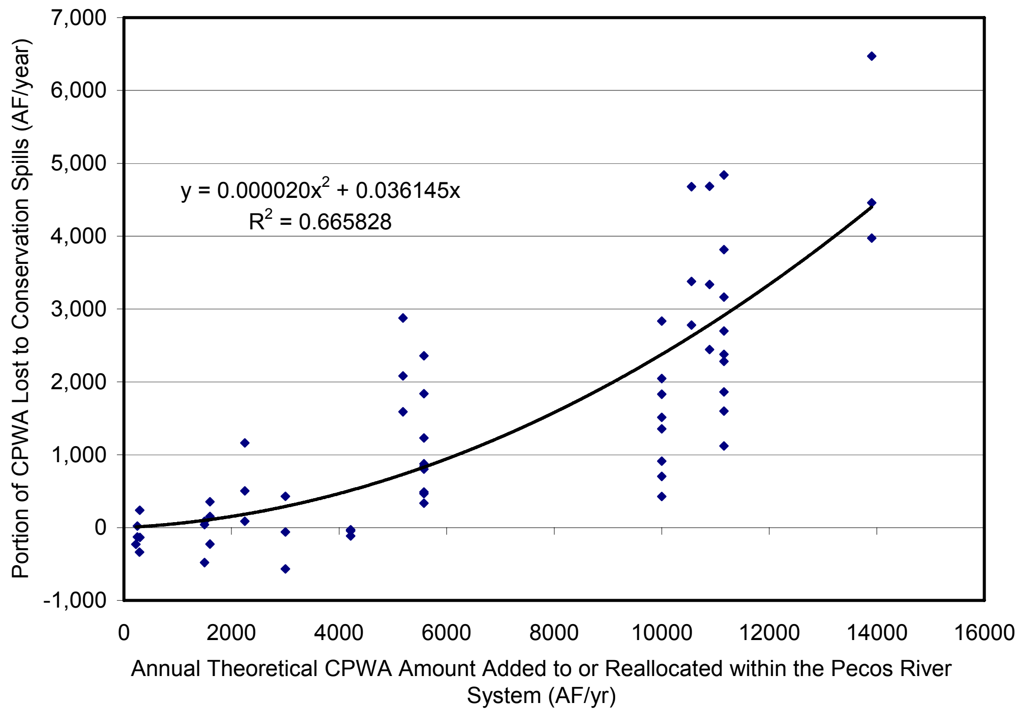

Figure 14. Theoretical CPWA Plotted Against the Portion of CPWA Lost to Spills

3.4 Superposition/Interpolation as a Function of Depletions

Although originally considered for interpolation of determining effectiveness of CPWA options combined with alternatives other than Taiban and Acme constant (the least and most depletive alternatives, respectively), output data indicates that the principle of superposition is not valid for CPWA options. Figure 15 shows an example of the poor linear correlation between net depletions to CID for an alternative and CPWA efficiency. Note in the figure that the efficiency also varies with added theoretical CPWA amount. No single set of CPWA options showed a satisfactory correlation with depletions to CID supply. Two main reasons account for the invalidation of the superposition principle. One reason is the random cyclical nature of conservation spills despite their strong correlation with increased alternative flow targets (Tetra Tech, 2003e) and their strong correlation with increased CPWA added or reallocated within the Pecos River System (Section 3.3.6). In addition, indirect effects of retirement can cause nonlinear responses for CPWA effectiveness, such as forbearance in FSID. For this reason, only ranges and averages of effective CPWA amounts should be used for planning purposes.

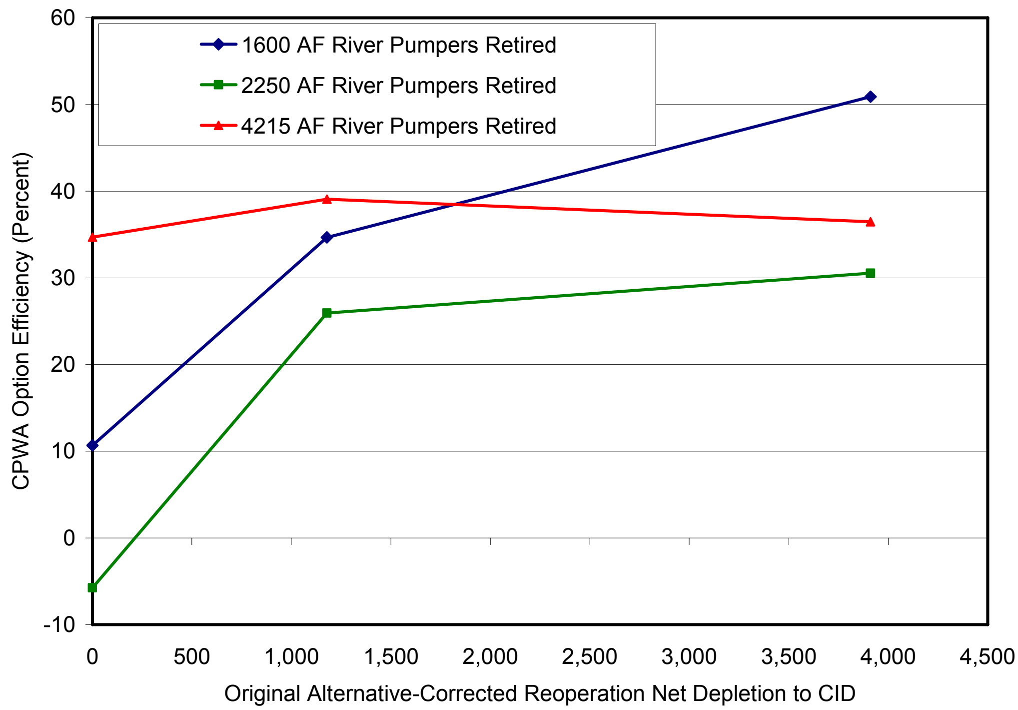

Figure 15. Alternative Net Depletions to CID plotted with CPWA Efficiency

4.0 Summary

CPWA modeling with the Pecos River RiverWare Model was used to determine effective CPWA amounts for A-list CPWA options defined for the Carlsbad Project Reoperations NEPA process.

The CPWA options that were modeled included surface water retirement in three major irrigation districts, groundwater retirement and subsequent pumping of those retired rights as CPWA, diversion reductions based on changing cropping patterns to lower use crops, and gravel pit pumping from an abandoned gravel pit in the Ft. Sumner area. CPWA scenarios were simulated with two different alternatives from the NEPA process, including Acme Constant and Taiban Constant. CPWA scenarios were also simulated against the Pre-91 NEPA baseline.

CPWA options were also reduced to determine the effective CPWA amount, or the amount of water that actually reached the Carlsbad Irrigation District for crop use effectively replacing the water depleted in transit for in stream habitat use by the Pecos bluntnose shiner. Effective CPWA amounts from non-project derived water sources were reduced by examining net depletions to CID supply. Effective CPWA amounts from project derived water sources were isolated by examining diversions normalized to the remaining acreage within the CID. Also, transit efficiencies of non-Project CPWA options from the CPWA source to Brantley reservoir were estimated.

5.0 References

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Pecos River RiverWare Model
Additional Water Acquisition Modeling
Documentation Report

Report on Modeling Assumptions and
Output Analysis for Determination of
Effectiveness of Additional Water Acquisitions

January 2006 Final Report

TETRA TECH, INC.

Table of Contents

1.0 Introduction

Additional water acquisition (AWA) options are explicitly designated for augmenting in-channel flows with the goal of meeting specified target flows for alternatives at times when Carlsbad Project supply coming into Santa Rosa and Sumner Reservoirs is less than demand.

The US Bureau of Reclamation (Reclamation) does not have authority to store water, other than the recently permitted 500 AF “fish conservation pool”, or take project water that has been stored for CID. In the event that bypass flows are insufficient to meet target flows, Reclamation cannot supplement the flows with stored water. Because of this, additional sources would be needed to meet the demands. The AWA water would be specifically acquired to augment flows for the shiner above the level of flow that can be achieved with bypasses. AWA is limited to the additional water that would be acquired with available resources to further augment flows but may not necessarily always meet the target.

Four AWA scenarios were investigated with the Pecos River RiverWare model (Tetra Tech, 2003b, 2003d, 2000b) which included water sources from both the A & B lists designated by WOOG (Reclamation, 2005b). These four scenarios were simulated with the Taiban and Acme Constant Alternatives and included water acquisition from the following locations:

- from Fort Sumner Irrigation District (FSID) located below Sumner Dam but whose supply originates above the dam,
- from diverters above Sumner Dam along the reach from Santa Rosa Dam to Puerto de Luna (PDL) (various upstream acequias),
- below Sumner Dam from a well field (referred to as the “Ft. Sumner Well Field” option), and
- through pumping from a gravel pit in the Ft. Sumner area.

Table 1 summarizes the AWA options that were modeled using RiverWare and the amount(s) of water that was modeled for each option.

Table 1. Modeled AWA Options and the Annual Amount Acquired

AWA Option	Modeled Amount (acre-feet per year)
Acquisition from FSID (purchase and lease)	1500, 3000, 9040
Aggregate of Sources from the PDL Reach	900, 2500, 4300
Ft. Sumner Well Field	1800
Ft. Sumner Gravel Pit Pumping	300 max (10 or 20 acre-feet per day)

2.0 Model assumptions and simulation of additional water acquisitions

Analysis of AWA water involved model simulations using the four water sources listed above to directly augment in-stream flows for the Pecos Bluntnose Shiner (PBNS). Likely available amounts, as estimated by the WOOG, were modeled to determine what flow frequency benefits might be realized for those volumes. In addition, AWA water was modeled to determine if net depletions or incidental benefits to CID occur as a result of using water directly for the PBNS. As with the Carlsbad Project Water Acquisition (CPWA—See EIS Technical Appendix 3.C) options, only the Pre-91 Baseline, the Taiban Constant and the Acme Constant alternatives were examined in combination with AWA options as these alternatives represent extremes in net depletions.

2.1 FSID Retirement and Forbearance (FSID-AWA)

FSID diverts water from the Pecos River from a low-head diversion dam located on the Pecos downstream of the Sumner Dam. Water is diverted during the irrigation season, typically from March 1 though October 31. With this AWA option, a portion of the water originally allocated to FSID would not be diverted but would remain in the main stream of the Pecos River. The amounts available for purchase and lease were combined to form the 1500 ac-ft and 3,000 ac-ft options. In addition, a volume of 9,040 acre-feet per year was also modeled as this represents the 2004 irrigation season average forbearance of 18.6 cfs.

For this AWA option, water is used for augmentation only when FSID diverts water, i.e. during the irrigation season. When the volumes of water listed above are dispersed over the 245 day irrigation season the result is a continuous flow of 3.08 cfs, 6.17 cfs and 18.06 cfs, respectively.

Only water that is bypassed through Sumner Reservoir (i.e. not stored in Sumner Reservoir for CID) is available to FSID for diversion. FSID has a maximum allotment of 100 cfs during the irrigation season, or a total of 48,595 ac-ft per season. Therefore the three options of 1,500 ac-ft, 3,000 ac-ft and 9,040 ac-ft represent 3.1%, 6.2% and 18.1% of FSID's maximum annual allotment.

FSID is entitled to 100 cfs, if that much is available as inflow to Sumner Dam. With this AWA option, the RiverWare model was set up such that 100 cfs minus the AWA forbearance would be diverted to FSID and the AWA forbearance would remain in the channel. In some cases, there is insufficient inflow to allow 100 cfs to be diverted to FSID. In those cases, the AWA forbearance would be reduced by the same ratio as the reduction in the FSID allotment. For example, if 80 cfs were available for diversion to FSID, that is 80 percent of the total entitlement, only 80 percent of the AWA water remained in the channel (2.47, 4.94, and 14.88 cfs respectively for this example).

2.2 Aggregate of Upstream Acequia Options above Sumner Dam (PDL-AWA)

The aggregate of upstream acequia water options above Sumner Dam amounted to 900 acre-feet per year, 3,000 acre-feet per year, and 4,300 acre-feet per year, or a continuous flow of 1.85 cfs, 5.14 cfs, and 8.85 cfs over the 245-day irrigation season. This water was modeled as entering the system at the upstream end of the Puerto de Luna (PDL) reach. This simulated diversions that would be acquired in that reach, such as forbearance from the PDL acequia, and diversions upstream of Santa Rosa (with the modeled assumption that the water would be bypassed through Santa Rosa Dam).

The PDL-AWA water was bypassed through Sumner Dam by increasing the Sumner outflow when water was bypassed for FSID (during the irrigation season). If bypass available from incoming Carlsbad Project Supply was already sufficient to meet the target, the bypass from Project supply was curbed by an amount equal to the AWA forbearance. During times of flood releases or block releases, efforts were not made to augment the outflow with the additional water acquired in the PDL reach.

The AWA forbearance above Sumner Dam was reduced by a prorated share of the loss for the total amount of flow in the Santa Rosa to PDL reach to account for gains or losses to that fraction of the water as it traveled through the PDL reach.

2.3 Ft. Sumner Well Field (FSWF-AWA)

The Ft. Sumner Well Field option is assumed to converge with the Pecos River downstream from the FSID diversion and upstream of the confluence with Taiban Creek. The pipeline would supply an annual volume of 1,800 acre-feet with a maximum discharge of 12 cfs to supplement the river flows for the PBNS. This water is assumed to be an annual amount that does not carry over from year to year.

Water from the well field was modeled as entering the system when it was needed to help augment flows in the channel below the FSID diversion. When the downstream demand needed to meet the target exceeds the incoming bypass supply, flow from the FSWF pipeline is released to the stream. Groundwater interactions with the Pecos River and depletions to the local groundwater aquifer were not modeled for this option.

This is a simplified version of how the pipeline would be operated and actual operations may be able to better utilize the additional water to avoid intermittency as well as maintain targets.

2.4 Gravel Pit Pumping (GP-AWA)

Pumping from the gravel pit in the Ft. Sumner area was also modeled as an AWA option. Pumped water was added to the model when bypass supply was insufficient to meet target demands. Pumping was subject to an assumed maximum of 300 acre-ft/year—the estimated gravel pit annual inflow. Two pumping rates out of the pit were modeled: one at 10 ac-ft per day or 5.04 cfs and a second at a higher rate of 20 ac-ft per day or 10.08 cfs. Losses were not applied to these rates, but it is likely a small percentage of this water would be lost in transit through FSID's drain system before reaching the Pecos River.

Water from the gravel pit was pumped into the system when needed to help augment bypass flows to meet alternative targets at Acme or Taiban. The need for the water was determined in the same manner as was done for the Ft. Sumner Well Field AWA option. Groundwater interactions with the Pecos River and depletions to the local groundwater aquifer were not modeled for this option.

3.0 Impacts of AWA scenarios

The impacts of AWA were analyzed for the four separate sources of AWA modeled using RiverWare. The focus of the analyses was on the effect of AWA on the occurrence of intermittency near Acme or improvements to flow durations, but the impact was also reviewed for the amount of time that target flows are met. While the purpose of AWA is not to offset net depletions to the Carlsbad Project supply, the effects of AWA options on net depletions to the Carlsbad Project supply were also analyzed.

Due to the small volumes considered with the AWA analysis, the additional water had little effect on flow frequency and intermittency. Forbearance from FSID for the Acme Constant alternative showed an average annual increase in days the target flow was met, ranging from 6 to 46 days per year depending on the volume of forbearance. However, FSID forbearance was the only AWA option that worsened intermittency, with 1.4 to 2.4 % more intermittency for the Acme Constant alternative with bypass operations alone.

The aggregate of water from PDL showed little to no change in intermittency and a 2 to 11 day per year increase in the number of days the target flow was met for the Acme Constant alternative. The Ft. Sumner Well Field also showed little to no change in intermittency and only a 2 day increase in the average annual number of days the target flow was met. The gravel pit pumping showed virtually no benefit for intermittency or annual increase in days that the target flow was met as compared to the Acme Constant alternative. Most of the AWA options showed a worsening of flow frequency and intermittency when coupled with the Taiban Constant alternative.

3.1 AWA from FSID

Intermittency

The benefit of AWA from FSID in regards to additional river flows is limited to the consumptive portion of FSID's water right. Much of the acquired water (69% on average) would eventually be in the river anyway as return flows. This effect combined with the expected conveyance losses to seepage and evapotranspiration would yield a negligible benefit for AWA from FSID. The occurrence of intermittency near Acme would not be reduced as a result of AWA from FSID. In fact, the model results indicate that zero flow would occur more often. With the reduction in return flows from FSID corresponding to AWA, the demand for bypasses would increase. For the Taiban Constant Alternative, these effects would also impact the amount of time that target flows are met. Expected impacts of AWA from FSID on intermittency and target flows are summarized in Tables 2 and 3 for the Taiban Constant and Acme Constant Alternatives, respectively, for the Acme gage.

Table 2. Impact of AWA from FSID with the Taiban Constant Alternative

AWA with Taiban Constant	Average Days per Year of Intermittency at Acme (no flow)		Average Days per Year that the Flow at the Target Location was Increased
	Alternative	Alternative with AWA	Alternative with AWA
FSID (1500 acre-feet/year)	3.3	5.8	-8.4
FSID (3000 acre-feet/year)	3.3	7.3	-10.7
FSID (9040 acre-feet/year)	3.3	5.6	-8.8

Table 3. Impact of AWA from FSID with the Acme Constant Alternative

AWA with Acme Constant	Average Days per Year of Intermittency at Acme (no flow)		Average Days per Year that the Flow at the Target Location was Increased
	Alternative	Alternative with AWA	Alternative with AWA
FSID (1500 acre-feet/year)	2.5	3.4	6.0
FSID (3000 acre-feet/year)	2.5	3.6	21.7
FSID (9040 acre-feet/year)	2.5	4.9	46.3

Flow Exceedance

Flow exceedance for the FSID AWA options combined with Taiban Constant is depicted in Figure 1. FSID AWA options with Acme Constant are shown in Figure 2. As with the tables, it is apparent from the plots that AWA from FSID is mostly detrimental to flow frequency at Acme since return flows from FSID are reduced and less total water is being released below the dam.

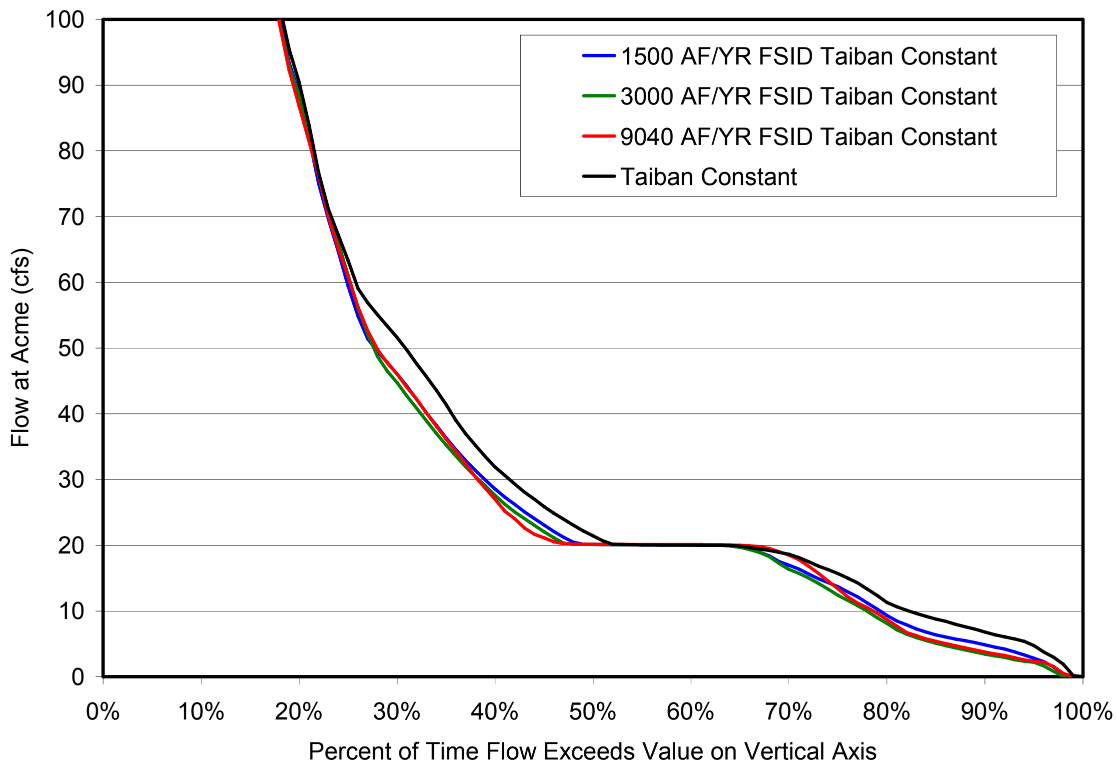

Figure 1. Flow Exceedance at Acme for the Taiban Constant Alternative with AWA from FSID.

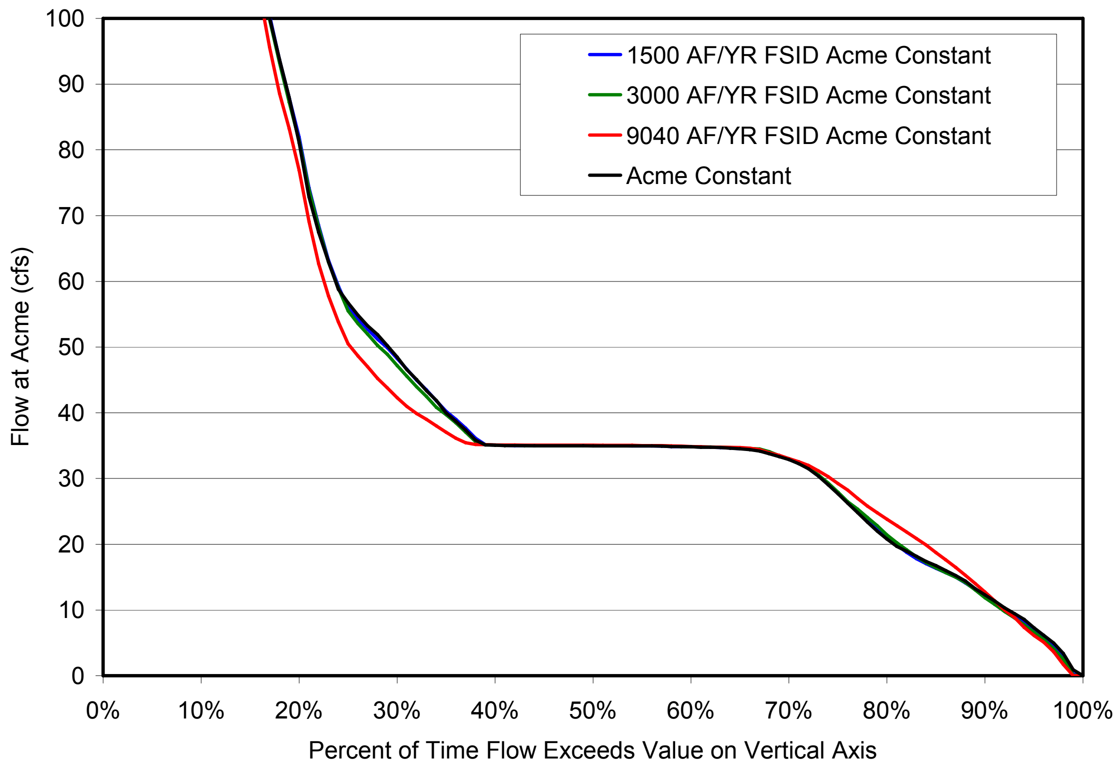

Figure 2. Flow Exceedance at Acme for the Acme Constant Alternative with AWA from FSID.

Net Depletions

NOTE: For a detailed description of net depletions including definitions and equations, refer to the "Results Memorandum for Alternative Modeling Using Bypass Water" in the Carlsbad Project Operations and Water Conservation EIS Technical Appendix.

.A portion of AWA from FSID supplies may end up in Brantley Reservoir and become part of the Carlsbad Project supply, or the change in operations associated with this AWA option may cause additional depletions to the Carlsbad Project Supply. The impacts are not only a function of how much AWA ends up in Brantley Reservoir but also a function of how AWA affects the demand for bypasses to meet target flows associated with an alternative. As FSID returns decrease, the demand for bypasses increases. These two factors combined yield variability in the impacts of AWA between alternatives. Timing and annual volume of block releases will also affect net depletions to Carlsbad project supplies when considering AWA from FSID among alternatives. The effects of AWA from FSID on net depletions are summarized in Table 4 for the Taiban Constant and Acme Constant Alternatives. It can be concluded from the results in Table 4 that alternatives that move larger volumes of water by block release (such as Taiban Constant) demonstrate increased efficiency of transmission of AWA to Brantley Reservoir.

Table 4. Impact of AWA from FSID on Net Depletions to the Carlsbad Project Supply

Source for AWA	Average Annual Net Depletion (acre-feet)			
	Acme Constant	Additional Depletion from AWA with Acme Constant	Taiban Constant	Additional Depletion from AWA with Taiban Constant
No AWA	3,900	---	1,200	---
FSID (1500 acre-feet/year)	4,300	400	1,200	0
FSID (3000 acre-feet/year)	3,900	0	700	-500
FSID (9040 acre-feet/year)	4,000	100	900	-300

3.2 AWA from Upstream Acequias - PDL

Intermittency

Agreements may be reached for AWA with various upstream acequias along the reach from Santa Rosa Dam to PDL. The conveyance losses associated with this option would significantly reduce the benefit realized near Acme. In fact, model results indicate that the occurrence of intermittency near Acme would not be reduced as a result of AWA from upstream acequias. Also, depending on the alternative, AWA from this option may adversely impact the amount of time that target flows are met. The impacts are summarized in Tables 5 and 6 for the Taiban Constant and Acme Constant Alternatives, respectively for the Acme gage.

Table 5. Impact of AWA from Acequias with the Taiban Constant Alternative

AWA with Taiban Constant	Average Days per Year of Intermittency at Acme (no flow)		Average Days per Year that the Flow at the Target Location was Increased
	Alternative	Alternative with AWA	Alternative with AWA
PDL (900 acre-feet/year)	3.3	4.4	-2.4
PDL (3000 acre-feet/year)	3.3	4.0	-1.2
PDL (4300 acre-feet/year)	3.3	3.6	-0.5

Table 6. Impact of AWA from Acequias with the Acme Constant Alternative

AWA with Acme Constant	Average Days per Year of Intermittency at Acme (no flow)		Average Days per Year that the Flow at the Target Location was Increased
	Alternative	Alternative with AWA	Alternative with AWA
PDL (900 acre-feet/year)	2.5	2.5	2.4
PDL (3000 acre-feet/year)	2.5	2.6	6.5
PDL (4300 acre-feet/year)	2.5	2.3	10.7

Flow Exceedance

Flow Exceedance plots for AWA options utilizing water from upstream acequias are shown in Figures 3 and 4. Figure 3 shows the combinations of AWA from acequias with the Taiban Constant alternative and Figure 4 shows those combinations with the Acme Constant alternative. The Taiban Constant alternative shows slight detriments to slight improvements in some of the flow ranges. The Acme Constant alternative shows improvements in all flow ranges. This difference is likely due to the AWA water from PDL combined with the larger bypasses of Acme Constant. With Taiban Constant, these AWA amounts are consumed by the break through flows in the reaches between Sumner and Acme much more readily (due to the lower flow levels in the river) with the Taiban Constant alternative than they are with the Acme Constant alternative.

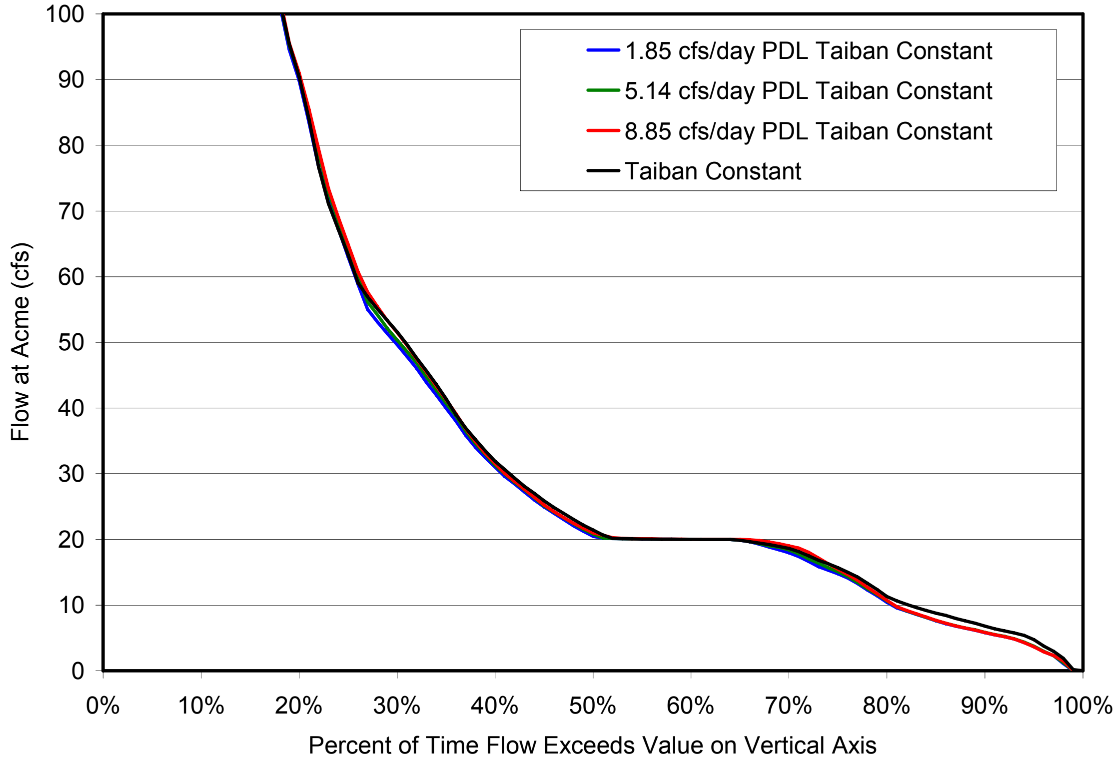

Figure 3. Flow Exceedance at Acme for the Taiban Constant Alternative with AWA from Upstream Acequias

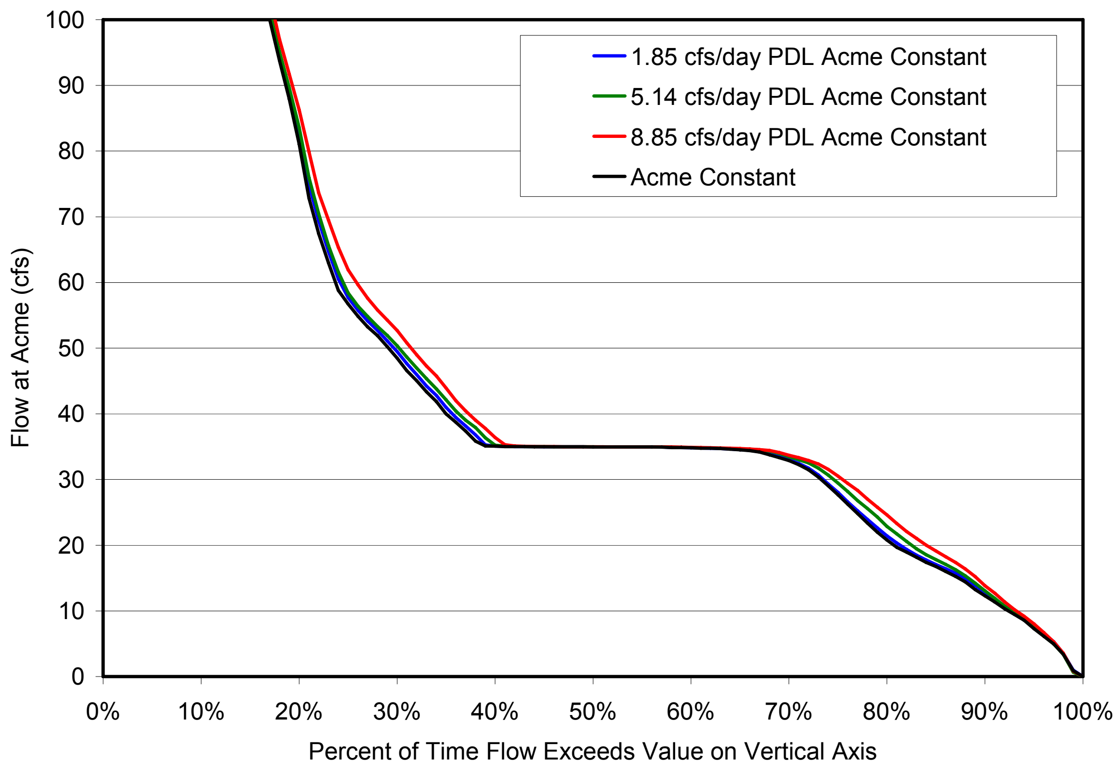

Figure 4. Flow Exceedance at Acme for the Acme Constant Alternative with AWA from Upstream Acequias

Net Depletions

AWA from upstream acequia districts would augment the Carlsbad Project Supply. Since all of the AWA from this source would be an effective gain to the river at the location of the source (i.e. the amount of water would not be effectively reduced based on return flows that would have been realized anyway as in the case of FSID), incidental benefits to the Carlsbad Project supply are always evident. The impacts of AWA from upstream acequia districts on net depletions are summarized in Table 7 for the Taiban Constant Alternative and Acme Constant Alternative.

Table 7. Impact of AWA from Acequia Districts on Net Depletions to the Carlsbad Project Supply

	Average Annual Net Depletion (acre-feet)			
AWA	Acme Constant	Additional Depletion from AWA with Acme Constant	Taiban Constant	Additional Depletion from AWA with Taiban Constant
No AWA	3,900	---	1,200	---
PDL (900 acre-feet/year)	3,700	-200	600	-600
PDL (3000 acre-feet/year)	3,200	-700	500	-700
PDL (4300 acre-feet/year)	3,200	-700	500	-700

3.3 AWA from Ft. Sumner Well Field

Intermittency

In the event that the Ft. Sumner Well Field is constructed and used to supplement in channel flows, there would be an expected decrease in the days of intermittency at the Acme gage for both the Taiban Constant and the Acme Constant Alternatives as detailed in Tables 8 and 9. Additionally, this AWA option lends a slight increase to the number of days per year that the flow target is met at the Acme gage.

Table 8. Impact of AWA from the Vaughn-Crockett Pipeline with the Taiban Constant Alternative

AWA with Taiban Constant	Average Days per Year of Intermittency at Acme (no flow)		Average Days per Year that the Flow at the Target Location was Increased
	Alternative	Alternative with AWA	Alternative with AWA
Ft. Sumner Well Field	3.3	3.1	1.0

Table 9. Impact of AWA from the Vaughn-Crockett Pipeline with the Acme Constant Alternative

AWA with Taiban Constant	Average Days per Year of Intermittency at Acme (no flow)		Average Days per Year that the Flow at the Target Location was Increased
	Alternative	Alternative with AWA	Alternative with AWA
Ft. Sumner Well Field	2.5	2.2	1.7

Flow Exceedance

Changes to the flow exceedance from the Ft. Sumner well field for the Taiban Constant and Acme Constant alternatives were imperceptible using a flow exceedance chart. For this reason, flow exceedance figures are not presented for this AWA option.

Net Depletions

The AWA from the Ft. Sumner Well Field adds enough water to the system to cause some small additional net depletions to the Carlsbad Project Supply. Most of the net depletion is due to differences in spills at Avalon Reservoir. Table 10 below summarized the results.

Table 10. Impact of AWA from Vaughn Crocket Pipeline on Net Depletions to the Carlsbad Project Supply

AWA	Average Annual Net Depletion (acre-feet)			
	Acme Constant	Additional Depletion from AWA with Acme Constant	Taiban Constant	Additional Depletion from AWA with Taiban Constant
No AWA	3,900	---	1,200	---
Vaughn Crockett Pipeline	4,000	100	1,000	200

3.4 AWA from Gravel Pit Pumping in the Ft. Sumner Area

Intermittency

The gravel pit in the Ft. Sumner area could be pumped to augment river flows, but this source would yield negligible results. Model simulations indicate that the available amount of water is too small to yield a significant change to flows near Acme. The effects of pumping from the

FSID Gravel Pit on the occurrence of intermittency and target flows near Acme are summarized in Tables 11 and 12.

Table 11. Impact of AWA from FSID Gravel Pit Pumping with the Taiban Constant Alternative

AWA with Taiban Constant	Average Days per Year of Intermittency at Acme (no flow)		Average Days per Year that the Flow at the Target Location was Increased
	Alternative	Alternative with AWA	Alternative with AWA
Ft. Sumner Gravel Pit (10 acre-feet/day)	3.3	3.3	0.0
Ft. Sumner Gravel Pit (20 acre-feet/day)	3.3	3.3	0.0

Table 12. Impact of AWA from FSID Gravel Pit Pumping with the Acme Constant Alternative

AWA with Acme Constant	Average Days per Year of Intermittency at Acme (no flow)		Average Days per Year that the Flow at the Target Location was Increased
	Alternative	Alternative with AWA	Alternative with AWA
Ft. Sumner Gravel Pit (10 acre-feet/day)	2.5	2.2	0.2
Ft. Sumner Gravel Pit (20 acre-feet/day)	2.5	2.2	0.2

Flow Exceedance

Changes to the flow exceedance from the gravel pit pumping for the Taiban Constant and Acme Constant alternatives were also imperceptible using a flow exceedance chart. For this reason, flow exceedance figures are also not presented for this AWA option.

Net Depletions

The AWA from the gravel pit adds a small amount of water to the system. This results in a slight impact on net depletions to the Carlsbad Project supply, as portrayed by the results presented in Table 13.

Table 13. Impact of AWA from FSID Gravel Pit on Net Depletions to the Carlsbad Project Supply

AWA	Average Annual Net Depletion (acre-feet)			
	Acme Constant	Additional Depletion from AWA with Acme Constant	Taiban Constant	Additional Depletion from AWA with Taiban Constant
No AWA	3,900	---	1,200	---
Gravel Pit (10 acre-feet/year)	4,100	200	1,100	-100
Gravel Pit (20 acre-feet/year)	3,900	0	1,100	-100

In addition to the four modeled AWA options, Table 14 on the next page contains a qualitative assessment of hydrologic effects of AWA options that weren't modeled for the Carlsbad Operations EIS. This includes all options that were B-listed by the WOOG in their ranking process.

4.0 Conclusions

AWA options were modeled for four different water sources with the Taiban and Acme Constant alternatives. Results indicated that AWA options have little benefit to flow duration, intermittency, or Carlsbad Project water supplies. AWA from FSID generally worsens flow duration and intermittency due to the reduced return flows from FSID and because less total water is released below the dam than would be with the alternative alone. AWA from upstream acequias did not improve intermittency, but showed some improvements to flow duration for Taiban Constant, and showed improvements in nearly all low-flow ranges for Acme Constant. AWA from the Ft. Sumner Well Field showed slight improvements to intermittency and time meeting targets for both alternatives, but changes to flow exceedance were negligible. Improvements in intermittency for AWA Gravel Pit pumping showed slight (Acme Constant) to no improvement (Taiban Constant) with a negligible improvement in achieving targets and flow duration.

Table 14. Qualitative Assessment of Hydrologic Effects for AWA Options that were not Modeled for the Carlsbad Operations EIS

Additional Water Acquisition B-List Qualitative Impacts

Designation	Option Name	Logistics and Qualitative Impacts
F	Import Canadian River Water	Water would be piped into Pecos River system and bypassed through Sumner Reservoir. Water would directly benefit the PBNS. Water would accrue to river below Santa Rosa Dam. Water would need to be managed and accounted for to keep separate from CID supply.
A-3	Groundwater Right Purchase-FSPA	Purchase of water rights in Fort Sumner Pivot Area. Alone this option will have little effect on increasing flows for the PBNS, although the interaction of groundwater in these reaches is poorly understood.
A-3X	Groundwater Right Purchase-FSPA (add. 40% inflat.)	Purchase of water rights in Fort Sumner Pivot Area. Alone this option will have little effect on increasing flows for the PBNS, although the interaction of groundwater in these reaches is poorly understood.
B-3	Groundwater Right Lease-FSPA	Purchase of water rights in Fort Sumner Pivot Area. Alone this option will have little effect on increasing flows for the PBNS, although the interaction of groundwater in these reaches is poorly understood.
A-5	Water Right Purchase-Above Santa Rosa	Would create additional inflow into Santa Rosa Reservoir augmenting available bypass supply for PBNS. Measurement and apportionment of retired rights and wet water (vs. CID supply) would require administrative policy.
K	Renegotiate Compact--Forebearance	Would require agreement with State of New Mexico for CID to hold onto upstream supply (increased conservation storage and diversion amounts) in exchange for forbearance in the Red Bluff Irrigation District (to lessen state line compact obligation). Would require additional agreement between CID and BOR for forbearance exchange for AWA (pays for bypass water upfront).
G-1	Range and Lower Watershed Management (adj. river upland)	Would increase base flows into Pecos River and its tributaries. Impacts would accrue both above and below Acme, so PBNS habitat may realize part of the benefit. Very difficult to quantify true amount of salvaged water
G-2	Range and Lower Watershed Management (adj. river upland)	Would increase base flows into Pecos River and its tributaries. Impacts would accrue both above and below Acme, so PBNS habitat may realize part of the benefit. Very difficult to quantify true amount of salvaged water
C-3	On Farm Conservation-FSPA	Most likely little or no effect on Pecos River system in short-term. Long-term affects of curbing groundwater pumping in this area are poorly understood.
E-1	Riparian Veg. Control (Salt Cedar)	Water would accrue into Santa Rosa and Sumner or directly into Pecos in Upper Critical Habitat. Quantifying actual salvage amounts are very difficult. Benefit of salvaged water complicated by Pecos Compact which requires 1/2 of any federally funded salvage to be delivered to Texas.
A-5X	Water Right Purchase-Above Santa Rosa (add. 40% inflat.)	Would create additional inflow into Santa Rosa Reservoir. Measurement and apportionment of retired rights and wet water (vs. CID supply) would require administrative policy.
E-2	Riparian Veg. Control (Replace RO with CW)	Water would accrue into Santa Rosa and Sumner or directly into Pecos in Upper Critical Habitat. Quantifying actual salvage amounts are very difficult. Benefit of salvaged water complicated by Pecos Compact which requires 1/2 of any federally funded salvage to be delivered to Texas.
B-5	Water Right Lease-Above Santa Rosa	Would create additional inflow into Santa Rosa Reservoir augmenting available bypass supply for PBNS. Measurement and apportionment of retired rights and wet water (vs. CID supply) would require administrative policy.
C-5	On Farm Conservation-Above Santa Rosa	Will increase in stream flow and bypass supply for PBNS, but will require saved water is not diverted or turned back. Hard to measure and manage. Will require accounting to segregate saved water from CID supply.
G-6	Range and Upper Watershed Management (forest thinning)	Would cause increase in mostly headwater inflows on main stem Pecos and on tributaries. Very difficult to quantify amounts. Upstream diverters would likely divert additional amounts before they were realized in lower reservoirs.
H-1	Evaporation Suppression (old meth.)-Santa Rosa and Sumner	If feasible, would have a direct benefit to both PBNS and CID. Difficult to quantitatively measure gains in water.
D-3	Change Cropping Patterns-FSPA (Small Grain)	Most likely little or no effect on Pecos River system in short-term. Long-term affects of curbing groundwater pumping in this area are poorly understood.
H-3	Evaporation Suppression (old meth.)-Sumner	If feasible, would have a direct benefit to both PBNS and CID. Difficult to quantitatively measure gains in water.
G-3	Range and Lower Watershed Management (adj. river upland)	Would increase base flows into Pecos River and its tributaries. Impacts would accrue both above and below Acme, so PBNS habitat may realize part of the benefit. Very difficult to quantify true amount of salvaged water
D-5	Change Cropping Patterns-Above Santa Rosa (Small Grain)	Will increase in stream flow, but will require saved water is turned back or not diverted. Hard to measure and manage. Will require accounting to segregate saved water from CID supply.
G-5	Range and Upper Watershed Management (forest thinning)	Would cause increase in mostly headwater inflows on main stem Pecos and on tributaries. Very difficult to quantify amounts. Upstream diverters would likely divert additional amounts before they were realized in lower reservoirs.
G-4	Range and Upper Watershed Management (forest thinning)	Would cause increase in mostly headwater inflows on main stem Pecos and on tributaries. Very difficult to quantify amounts. Upstream diverters would likely divert additional amounts before they were realized in lower reservoirs.
H-2	Evaporation Suppression (old meth.)-Santa Rosa	If feasible, would have a direct benefit to both PBNS and CID. Difficult to quantitatively measure gains in water.
H-4	Evaporation Suppression (new meth.)-Santa Rosa and Sumner	If feasible, would have a direct benefit to both PBNS and CID. Difficult to quantitatively measure gains in water.
H-6	Evaporation Suppression (new meth.)-Sumner	If feasible, would have a direct benefit to both PBNS and CID. Difficult to quantitatively measure gains in water.
H-5	Evaporation Suppression (new meth.)-Santa Rosa	If feasible, would have a direct benefit to both PBNS and CID. Difficult to quantitatively measure gains in water.

5.0 References

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Technical Addendum to the:

Carlsbad Project Water Operations and Water Supply Conservation Environmental Impact Statement

New Mexico-Texas Stateline Modeling and Post-Processing Report

January 2006

Prepared by Hydrosphere Resource Consultants, Inc.

HYDROSPHERE
Resource Consultants

TABLE OF CONTENTS

1.0 Introduction

As part of the Pecos River Carlsbad Project Water Operations and Water Supply Conservation NEPA Process, several resource indicators were developed for use in evaluating operational alternatives. This memo addresses the assumptions and methods used to compute impacts to one of those resource indicators, flow at the New Mexico-Texas Stateline, as well as summary results.

The State of New Mexico has obligations to deliver water to the New Mexico-Texas Stateline under the Pecos River Compact. While New Mexico may obtain a credit for over-delivery, it is not allowed to accrue a debt. Although the Compact itself is not indicated as a primary resource of interest as defined in the purpose and need for the EIS, it nevertheless is included as part of the cumulative impacts of the project, and may be a constraining influence on EIS alternatives and a driving force behind requirements for offsetting adverse impacts. Flows at the Texas-New Mexico Stateline are thus a resource of interest and model simulation results are evaluated to determine impacts to this resource.

2.0 Summary of Alternatives Modeling and Post-Processing

To evaluate the impacts of NEPA alternatives to reoperate Sumner Dam for the Pecos Bluntnose Shiner (PBNS), the Hydrology/Water Operations Work Group (HWG) modeled alternatives using the Pecos River Decision Support System (PRDSS) (Hydrology Work Group, 2003 and 2004; Hydrosphere, 2001 and 2005; Hydrosphere and Tetra Tech, Inc, 2003a and 2003b). The PRDSS consists of a RiverWare surface water model, two MODFLOW groundwater models, and an MSAccess-based output post-processor/data reformatter. After the PRDSS was run, model outputs were post-processed, saved in an MSAccess results database, and results for requested resources of interest distributed to EIS work groups. This document focus primarily on the portions of the PRDSS used to simulate the Pecos River from Avalon Reservoir to the Stateline.

3.0 Modeling Stateline Flows

Specific to Stateline flow modeling, a suite of three models and a data processor simulate groundwater and surface water hydrology and operations from Avalon Reservoir to the New Mexico-Texas Stateline. This suite includes the:

- Pecos River RiverWare Model;
- Carlsbad Area Groundwater Model (CAGW);
- The Red Bluff Accounting Model (RBAM); and
- Data Processing Tool (DPT).

Results are stored in an MSAccess database where additional post-processing occurs. Excel results files are dynamically linked to the results database for reporting.

<u>The Pecos River RiverWare Model</u> models diversions from Lake Avalon to the Carlsbad Irrigation District (CID) based on available surface water supplies and CID demand. RiverWare also computes conservation spills and seepage from Avalon Dam. Diversion and seepage values are processed for input to the CAGW groundwater model. Avalon conservation spills are input to the RBAM model.

Individual RiverWare surface water models (run on a daily timestep) and rulesets were created for each alternative (a summary alternative matrix presented in attachment A). Alternatives vary mostly by stipulations for flow targets in the PBNS Upper Critical Habitat and at two target gages. More specific details regarding how alternatives were modeled can be found in the EIS.

The Carlsbad Area Groundwater Model (CAGW) is a 2-layer MODFLOW model that simulates impacts of surface irrigation and well pumping in the Carlsbad area on gains to the Pecos River below Avalon Dam. Diversions to CID from Avalon are translated into components including transit losses, incidental depletions, consumptive irrigation requirements, and return flows. Surface water diversions are used to determine if supplemental well pumping to augment Carlsbad Project supply is required, and the magnitude and timing of the pumping. Seepage from Avalon contributes to the Carlsbad ground water system. Return flows, supplemental pumping and base inflows are then routed through the Carlsbad Basin groundwater system before entering the Pecos River.

The Red Bluff Accounting Model (RBAM) provides a monthly and annual analysis of deliveries to the New Mexico-Texas Stateline, incorporating data from both the CAGW and RiverWare models. It aggregates and applies a 5% transit loss to the daily conservation spills (from RiverWare) from Avalon Dam to the Pecos River. Avalon spills are then combined with the monthly seepage into the Pecos River from the Carlsbad area (from CAGW), other tributary inflows, wastewater treatment plant effluent, and miscellaneous depletions to estimate Stateline flows.

The Data Processing Tool (DPT) handles input/output processing for the movement of data between the RiverWare model, CAGW and RBAM. The DPT calculates well pumping in the basin based on monthly farm deliveries aggregated from RiverWare output. It also calculates other influences on the aquifer including irrigation return flows, delivery seepage, and precipitation recharge, and builds the .WEL and .RCH stress files for input into the CAGW MODFLOW Model (the CAGW model is run separately outside the DPT). The DPT then aggregates the CAGW modeled gains to the Pecos River to monthly values for input into RBAM. RBAM, which resides inside the DPT, uses these data to generate monthly flows at the New Mexico-Texas Stateline, and the DPT then exports the Stateline flows on an annual basis for incorporation into the post-processing database.

The Post-Processing Database stores results for all resource indicators and requested model outputs. Additional post-processing occurs in this database, which is linked dynamically to reporting files.

4.0 Components of Texas-New Mexico Stateline Flows

Within the current suite of models used to model the basin, Pecos River flows at the Texas-New Mexico Stateline are comprised of:

- Avalon Reservoir Conservation Spills (from RiverWare);
- Base inflows and return flows from the Carlsbad area (from CAGW);
- Other tributary inflows between Avalon Dam and the Red Bluff gage (from RBAM); and
- Delaware River Inflows (from RBAM)

Fixed Stateline Components

Other than gains estimated from the CAGW model and Avalon conservation spills from RiverWare, inflows to the Pecos River between Avalon and the Stateline do not change between NEPA alternatives. Data sources for these inflows are many and include: gage data, data backed out from gage data, and results of regression analyses. Fixed inflows include the following:

- Dark Canyon Arroyo;
- Black River;
- Waste Water Treatment Plant WWTP) Effluent; and
- Delaware River.

Black River inflows are calculated in the DPT as Black River above Malaga gaged flows minus Black River canal diversions. Additional details can be found in the Pecos River Data Processing Tool Report (PR DPT) (Hydrosphere, 2005).

Variable Stateline Components

Avalon conservation spills and CAGW gains are not fixed and are influenced by a variety of factors, which change according to operational alternative.

Avalon Conservation Spills: Under all NEPA alternatives, the only downstream releases from Avalon Dam are conservation spills. Spills may occur when an individual reservoir's conservation storage limit is exceeded or when the total Carlsbad Project storage is exceeded. The magnitude and frequency of spills may be influenced by operational changes, such as timing of block releases or bypass flows for Pecos Bluntnose Shiner habitat.
Under cumulative impacts, additional releases from Avalon for the "Settlement Agreement[9]" would allow the New Mexico Interstate Stream Commission to release their share of Carlsbad Project water rights from Avalon downstream to the Stateline under certain conditions. Settlement Agreement releases were not modeled for this EIS.

CAGW Gains: CAGW gains are affected by a variety of factors including CID demands and deliveries, supplemental well pumping, and groundwater baseflows. When Carlsbad Project surface water supplies are low, "supplemental pumping" of groundwater is used to supplement supplies. This causes additional depletions to the return flows from irrigation, as well as depletions to the native groundwater that would otherwise seep into the Pecos River. Return flows from CID and base inflows from the underlying aquifer contribute significantly to Pecos River flows below Lake Avalon.

5.0 Net Depletions to the "New Mexico-Texas Stateline Flows" Resource Indicator

Model simulation results are not intended to predict future hydrologic conditions; rather they predict differences in hydrologic conditions in the basin resulting from different management actions. The evaluation process involves simulating a "baseline" scenario (the Pre-91 Baseline alternative) as well as alternative scenarios that represent operational changes. This provides a baseline condition for the resource indicators against which impacts caused by changing operations may be evaluated. Basin operational rules are then modified to reflect each proposed alternative scenario. The "net depletions", or loss of water, under an alternative

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[9] Entered into on March 25, 2003 by the state of New Mexico, the New Mexico Interstate Stream Commission, the United States of America, the Carlsbad Irrigation District, and the Pecos Valley Artesian Conservancy District.

scenario as compared to the Pre-91 Baseline is used here to represent this change in the "value" of the resource. Net depletions are shown as positive numbers when there is an adverse impact. A negative net depletion signifies a gain in water under the proposed alternative scenario. Net depletions to Stateline flows are the decrease in flows at the New Mexico-Texas Stateline for an alternative in comparison to the Pre-91 Baseline model run which does not include bypasses for the fish.

Net depletions to Stateline flows are primarily impacted by changes to CAGW gains below Avalon Dam and changes to spills from Avalon Dam. If an alternative impacts the delivery of water to CID, CAGW gains are impacted. If an alternative affects the magnitude of spills from Brantley Dam (and Avalon Dam) as conservation or project storage limits are exceeded, Stateline flows are affected. Average annual net depletions to Stateline flows were determined for each alternative.

In modeling alternatives, RiverWare block release rules were not adjusted to reflect changes in operational policies which may occur as a result of bypasses. As a result, the timing of modeled spills may be unrealistically skewed. To eliminate large variations in spills between individual years, Carlsbad Project net depletions were "corrected". Modeled spills from Avalon Dam during that year were subtracted and the average annual spills were added. Net depletions to Stateline flow (corrected) are calculated as:

$$\begin{array}{c}\textbf{Annual Corrected}\\ \textbf{Net Depletion to}\\ \textbf{Stateline Flows}\end{array} = \begin{array}{c}\textbf{Annual Net}\\ \textbf{Depletion to}\\ \textbf{Stateline Flow}\end{array} - \begin{array}{c}\textbf{Annual Net}\\ \textbf{Depletion to}\\ \textbf{Avalon Spills}\end{array} + \begin{array}{c}\textbf{60 Year}\\ \textbf{Average Net}\\ \textbf{Depletion to}\\ \textbf{Avalon Spills}\end{array}$$

Figure 1 shows Stateline net depletions before and after being "corrected" for the Taiban Constant alternative. Prior to being corrected, annual net depletions fluctuated greatly between years. By correcting net depletions annual values were smoothed. Average annual net depletions remain the same under both methodologies. All Stateline net depletions presented in the EIS are "corrected".

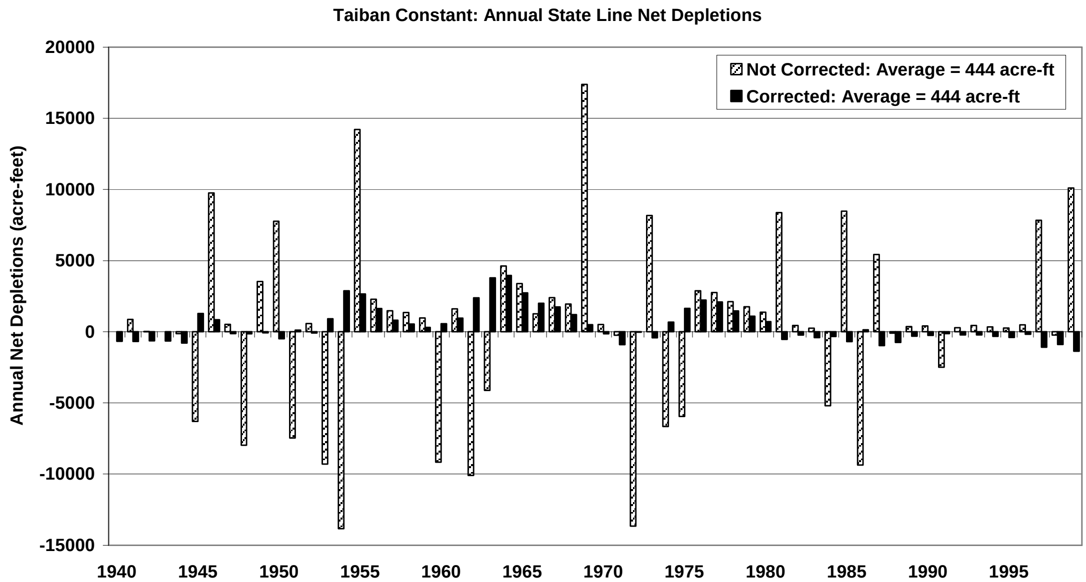

Figure 1. Comparison of annual "corrected" and "not corrected" Stateline net depletions

6.0 Bypass Operations Stateline Results

Figure 2 shows the average annual net depletions to Stateline flow results, rounded to the nearest 100 acre-feet, for bypass operations model simulations with additional results provided in Table 1. Figure 3 demonstrates the correlation between the average annual depletion and the effective Acme flow target[10]. The results show that alternatives with higher flow targets tend to exhibit higher net depletions. Acme Constant, Acme Variable and Taiban Variable HRS[11] alternatives exhibit the highest average annual net depletions to Stateline flows, whereas the Taiban Constant and Critical Habitat Alternatives yield the lowest net depletions.

Looking at the specific components of Stateline flows (Table 1), all bypass alternatives showed net depletions to CAGW gains. As Carlsbad Project supply decreases, supplemental pumping increases leading to lower return flows. Fewer diversions to CID also lead to smaller return flows from irrigated lands. These decreases were slightly offset by fewer spills for most alternatives, with the exception of No Action and Taiban Variable HRS.

[10] The effective Acme flow target is the alternative's flow target expressed at Acme. For alternatives with Acme targets, this the flow target. For alternatives with flow targets at other locations, targets are converted to Acme flows taking river gains and losses into account.
[11] The Taiban Variable alternative has summer targets which vary. The alternative identified as Taiban Variable HRS has a summer target of 55 cfs. The MRS alternative has a summer target of 45 cfs and the LRS alternative has a summer target of 40 cfs.

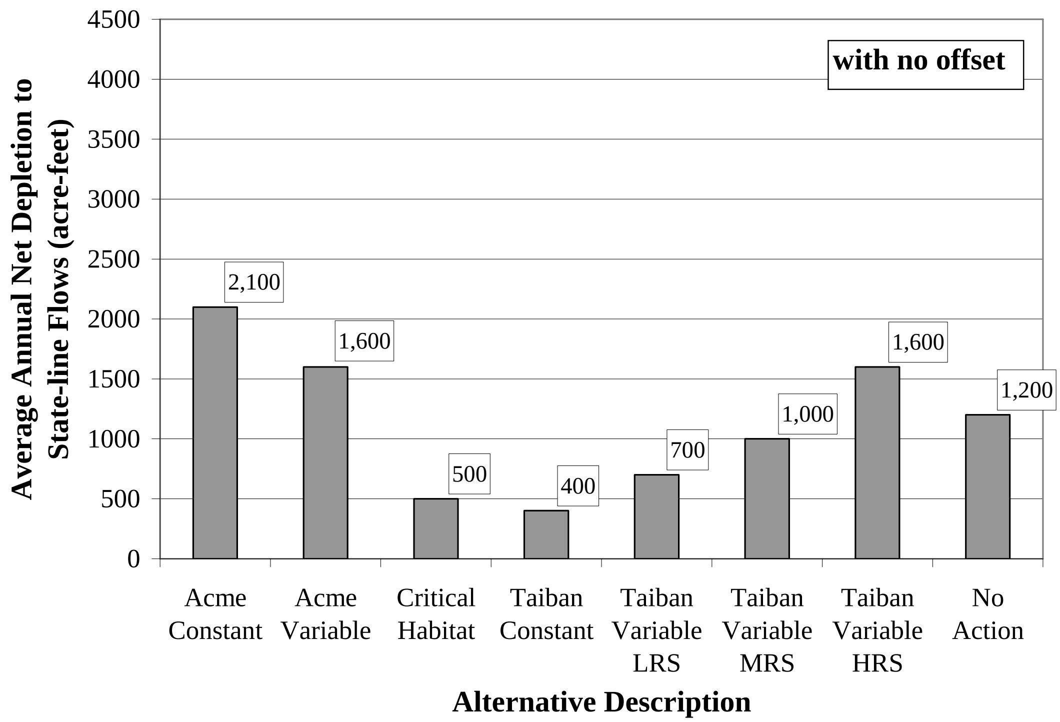

Figure 2. Average Annual Net Depletions to Stateline Flows for Each Alternative with No Water Offset

Table 1: Annual Stateline flow and selected component results

Alternative / Baseline	Net Depletions to Stateline Flows and Components [1] (acre-feet/year)						
	60-year Averages			Max. and Min. Net Depletions to Stateline Flows			
	Stateline Flows	CAGW Gains	Avalon Conservation Spills	Maximum Net Depletion to Stateline Flows	Maximum Occurs in Modeled Year	Minimum Net Depletion to Stateline Flows	Minimum Occurs in Modeled Year
Pre-91	NA	NA	NA	NA	NA	NA	NA
Acme Constant	2100	3000	-920	5400	1976	-1200	1941
Acme Variable	1600	2300	-720	4900	1976	-1000	1941
Critical Habitat	530	1100	-580	4000	1964	-1300	1999
Taiban Const.	440	1100	-660	4000	1964	-1400	1999
Taiban Var. LRS	690	1100	-400	4400	1964	-1100	1999
Taiban Var. MRS	1000	1300	-320	4600	1976	-770	1999
Taiban Var. HRS	1600	1400	210	5300	1964	-150	1950
No Action	1200	1200	13	3000	1975	-440	1941

[1] Results are presented with two significant figures; subsequently, summed components do not exactly match the totals.

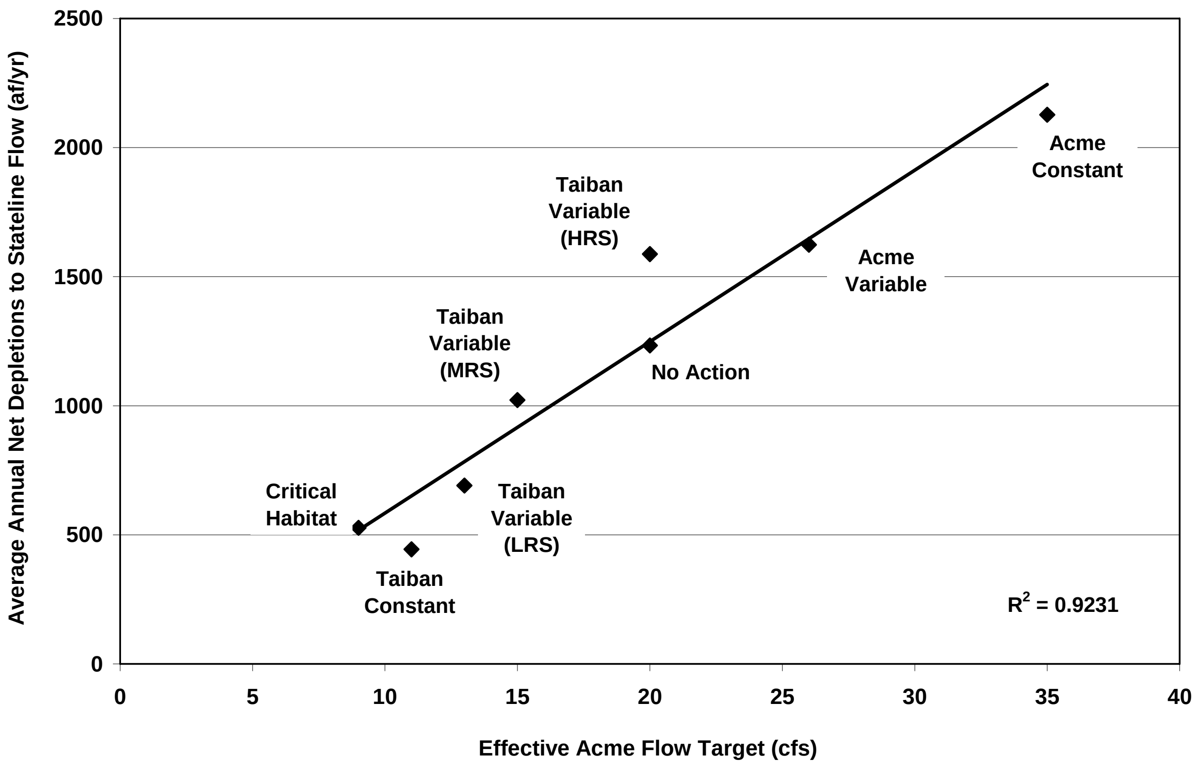

Figure 3. Average annual net depletions to Stateline flows as a function of effective Acme flow target.

7.0 Stateline Flows for Alternatives with Water Acquisition Options

One of the purposes of the Proposed Action is to conserve the Carlsbad Project water supply. Therefore, net depletions to the Carlsbad Project's supply caused by bypass operations to benefit the PBNS need to be "offset." Options for acquiring additional water (CPWA options[12]) were developed explicitly for the purpose of offsetting net depletions to the Carlsbad Project water supply caused by the re-operation of Sumner Dam for the Pecos bluntnose shiner.

7.1 Modeling Selected "A-List" CPWA Options to the Stateline

CPWA options were evaluated for how effective they were in offsetting net depletions to the Carlsbad Project. Regarding impacts on Stateline flows, generally, if an option offsets the net depletion to the Carlsbad Project supply, the net depletion at the Stateline would also be reduced. However, if the offset water source is directly from retirement of water rights within the Carlsbad Project or changes to CID cropping patterns, CAGW gains to the river are impacted. Additional spills may not make up for the decreases in CAGW gains downstream from Avalon Dam. For these reasons, offset options involving retirement of Carlsbad Project water rights or changes to CID cropping patterns were modeled to the Stateline.

To determine the effect of water offsets (CPWA) options on Stateline flows, the PRDSS was run to the Stateline for several A-list CPWA options in combination with three of the bypass

[12] Carlsbad Project Water Acquisition options

operations alternatives (Taiban Constant, Acme Constant, and Pre-91 Baseline). Table 2 shows the combinations of fish alternatives and CPWA options which were evaluated in the "first tier" of model simulations. These CPWA options were selected as those most likely to show a significant impact to Stateline flows, and to provide a range of impacts within which other similar CPWA options would be expected to fall. To maximize potential impacts, CID 3,000 acre retirement options, rather than 1,500 acre scenarios, were modeled. Assumptions used to model these CPWA options to the Stateline are listed under "Modeling Assumptions/Notes" in Table 2. Note that water applied to acreage with new crop patterns (very low and medium water use) is assumed to be fully consumed so there are no return flows to the river from these lands.

Table 2. Water acquisition options modeled to the Stateline

Fish Alternative / CPWA Combo	Modeling Assumptions/Notes
Very Low Water Use CID Crop Pattern	Expected maximum net depletion of all CID crop CPWA options. Cropping pattern change applied to 25% (5,000 of 20,000 acres) of CID's irrigated land. Reduction in consumptive irrigation requirements (CIR) is assumed to be fully consumed by new crops. Main/lateral losses are accounted for, but there are no on-farm incidental depletions or return flows. Delivery efficiency is unchanged. Lands under very low water use crops are not irrigated by supplemental wells.
Medium Water Use CID Crop Pattern	Expected minimum net depletion of all CID crop CPWA options. Cropping pattern change applied to 25% (5,000 of 20,000 acres) of CID's irrigated land. Reduction in consumptive irrigation requirements (CIR) is assumed to be fully consumed by new crops. Main/lateral losses are accounted for, but there are no on-farm incidental depletions or return flows. Delivery efficiency is unchanged. Lands under medium water use crops are not irrigated by supplemental wells.
3000 CID acres retired (actual only)	Actual irrigated acreage reduced from 20,000 acres to 17,000 acres, with no reduction in allotment acreage (25,055 acres). Retired lands are not irrigated by supplemental wells.
3000 CID acres retired (actual, and entitlement by constant)	Actual irrigated acreage is reduced from 20,000 acres to 17,000 acres, with a reduction in allotment acreage from 25,055 to 22,055 acres. Retired acreage water is redistributed to other irrigators. Retired lands are not irrigated by supplemental wells.

After the RiverWare model was run[3] for the specified CPWA options, the water diverted to new crops was subtracted from total CID diversions in the DPT. The remaining diversions were applied to acreage under the original crop pattern. Because water applied to new crop patterns was assumed to be fully consumed and no supplemental pumping occurred on new crop acreage, this water was not considered when determining CAGW gains. Supplemental pumping was calculated by comparing CID deliveries (diversions minus canal losses) to lands under the original crop pattern to the unmet allotment entitlement. The CAGW model was then run using those surface water and pumping stresses, and the modeled stream gains generated by CAGW were run through the Red Bluff Accounting Model to estimate Stateline Flows.

7.2 CPWA Stateline Modeling Results

Table 3 shows the average annual net depletions (rounded to two significant digits) to Stateline flows and primary components for the CPWA options which were modeled to the Stateline. Net Depletions to Stateline flows, Avalon spills and CAGW gains were calculated by subtracting CPWA options results from the Pre-91 Baseline results. Gains to Stateline flow due to offsets were calculated as the alternative's net depletion (e.g., Acme Constant with bypass operations

[3] For specifics on RiverWare modeling of CPWA options, see the Pecos River RiverWare Model Offset Modeling Documentation Report (Tetra Tech, 2005)

only) minus the net depletion for the alternative's CPWA options (e.g., Acme Constant Very Low Water Use CID Crop Pattern).

Table 3. CPWA Offset Modeling: Stateline Results

CPWA Offset Modeling: Stateline Results[1]				
	Average Annual Net Depletions (AF/yr)			Gains to Stateline Flow Due to Offset
Alternative and CPWA Option	Stateline Flow	Avalon Spills	CAGW Return Flows	
Acme Constant (without offset--used for offset determination):	2100	-920	3000	NA
Taiban Constant (without offset--used for offset determination):	440	-660	1100	NA
Pre-91(without offset--used for offset determination):	NA	NA	NA	NA
Acme Constant w/L-3 Very Low Water Use CID Crop Pattern:	-220	-4900	4400	2300
Taiban Constant w/L-3 Very Low Water Use CID Crop Pattern:	-2200	-5100	2700	2600
Pre-91 w/L-3 Very Low Water Use CID Crop Pattern:	-3100	-6500	3000	3100
Acme Constant w/L-4 Medium Water Use CID Crop Pattern:	3200	-2500	5600	-1100
Taiban Constant w/L-4 Medium Water Use CID Crop Pattern:	1300	-2700	3900	-840
Pre-91 w/L-4 Medium Water Use CID Crop Pattern:	830	-2900	3600	-830
Acme Constant w/3000 CID acres retired (actual only):	-17	-3600	3400	2100
Taiban Constant w/3000 CID acres retired (actual only):	-2300	-4500	2000	2700
Pre-91 w/3000 CID acres retired (actual only):	-2900	-4800	1700	2900
AC w/3000 CID acres retired (actual, and entitlement by constant):	-900	-2500	1500	3000
TC w/3000 CID acres retired (actual, and entitlement by constant):	-3000	-2900	-210	3500
Pre-91 w/3000 CID acres retired (acutal, and entitlement by constant):	-3500	-3200	-450	3500

[1] Results are only presented with two significant figures; subsequently, summed components do not exactly match the totals presented in this table.

When looking at results, it is the CPWA option's relative impact on spills and CAGW gains that determines whether there is a depletion to Stateline flows. The very low water use CID crop pattern and both land retirement options all resulted in increased Stateline flows. The medium water use CID crop pattern options are the only CPWA options which led to net depletions to Stateline flows. For the medium water use crop pattern options increases in spills were not sufficient to offset decreases in CAGW gains. Compared to the very low water use crop pattern CPWA options (which saw increases in Stateline flows), more water was diverted to medium water use crop pattern acreage and fully consumed, leaving less available in storage for future diversions or to spill.

CID land retirement options positively affected average annual Stateline flows, with increases ranging from 17 acre-ft/year for the Acme Constant w/3000 CID acres retired (actual only) option to 3,500 acre-ft/year for the Pre-91 Baseline w/3000 CID acres retired (actual, and entitlement by constant) option. Land retirement options where the total irrigated acreage was also reduced ("actual, and entitlement by constant" options) led to slightly greater Stateline flows than for land retirement options where the irrigated acreage was not reduced ("actual only" options). Spills from Avalon reservoir increased under all land retirement options, with greater increases for "actual only" options. Water from retired lands was not redistributed to other irrigators for "actual only" options leaving more water in storage and increasing the likelihood of a spill. Related to this are the net depletions to CAGW gains for all "actual only" retirement options. Less water was applied to irrigated lands so less water returned. All of the "actual, and entitlement by constant" options showed net increases to CAGW gains. This is because water from retired lands was redistributed and allocated to other irrigators which led to slight increases in gains.

Within each set of results (without offset, very low water use crop pattern, medium water use crop pattern, "actual only" retirement, and "actual, and entitlement by constant" land retirement) there are consistent relationships between the Pre-91 Baseline, Acme Constant and Taiban Constant alternatives. Increases to Stateline flows are smallest for the Acme Constant and greatest for Pre-91 Baseline options. Though net depletions are positive for medium water use crop pattern options, this pattern of less water at the Stateline for the Acme Constant alternative, followed by Taiban Constant and the Pre-91 Baseline alternatives persists.

8.0 References

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ATTACHMENT A: Summary Alternative Matrix

Carlsbad Project Water Operations and Water Supply Conservation EIS Alternatives												
	{-----------------Range of Flows ----------------------}						{----------------------------------Block Releases-------------------------------}					
	{-----Dry-----}		{-----Average-----}		{---Wet---}							
Alternative Designation	**Winter Target**	**Summer Target**	**Winter Target**	**Summer Target**	**Winter Target**	**Summer Target**	**Duration**	**Frequency**	**Magnitude**	**Ramp Down**	**Delivery**	**Time of Year**
Taiban Constant	35 cfs @ Taiban	35 cfs @ Taiban. Use pumps to prevent intermittency @ Acme	35 cfs @ Taiban	35 cfs @ Taiban. Use pumps to prevent intermittency @ Acme	35 cfs @ Taiban	35 cfs @ Taiban. Use pumps to prevent intermittency @ Acme	15 day max	On CID demand, but space out as long as possible	On CID demand	None	Maximum Efficiency	On CID demand – avoid releases during 6 weeks around August 1st
Taiban Variable	35 cfs @ Taiban	45cfs, -5, +10 @Taiban.	35 cfs @ Taiban	45cfs, -5, +10 @Taiban.	35 cfs @ Taiban	45cfs, -5, +10 @Taiban.	15 day max	On CID demand, but space out as long as possible	On CID demand	None	Maximum Efficiency	On CID demand – avoid releases during 6 weeks around August 1st
Acme Constant	35 cfs Acme	35 cfs Acme	35 cfs Acme	35 cfs Acme	35 cfs Acme	35 cfs Acme	15 day max	On CID demand, but space out as long as possible	On CID demand	None	Maximum Efficiency	On CID demand – avoid releases during 6 weeks around August 1st
Acme Variable	35 cfs Acme	12 cfs Acme	35 cfs Acme	24 cfs Acme	35 cfs Acme	48 cfs Acme	15 day max	On CID demand, but space out as long as possible	On CID demand	None	Maximum Efficiency	On CID demand – avoid releases during 6 weeks around August 1st
Critical Habitat	35 cfs Taiban Minimum	Critical Habitat Kept Wet; Avoid Intermittency @ Acme	35 cfs Taiban Minimum	5 cfs Acme	35 cfs Taiban Minimum	10 cfs Acme	15 day max	On CID demand, but space out as long as possible	On CID demand	None	Maximum Efficiency	On CID demand – avoid releases during 6 weeks around August 1st
No Action (Current Operations, 2003-2006 Biological Opinion)	35 cfs Acme	Upper Critical Habitat Kept Wet; Avoid Intermittency @ Acme	35 cfs Acme	20 cfs Acme	35 cfs Acme	35 cfs Acme	15 day max at peak. 65 days per year.	Space out to 14 + days apart	1200 cfs	None	Maximum Efficiency	No winter. On CID demand

Notes:

Reflects screening by the Alternatives Workgroup on 9/18/03 with 9/24/03 input from the Biology Workgroup and changes from 12/04/03 meeting.

Screening focused on flows and releases. Specific habitat restoration and conservation measures were not evaluated.

Unless specified differently in an alternative, all alternatives would have the following actions incorporated: (Some may require additional project-specific NEPA analysis)

- ✓ Offset all depletions through actions and priorities developed by the WOOG Group.
- ✓ Establishment and management of a conservation pool in Fort Sumner and Santa Rosa Reservoirs.
- ✓ Creation of a management plan addressing monitoring of the flow targets and establishing procedures, mitigative actions and sources of water available in case flow targets are threatened.
- ✓ Execution of an agreement document among the agencies governing the conservation pool and adaptive management plan

The following conservation actions would be considered by the appropriate agencies: (Some may require additional project-specific NEPA analysis)

- ✓ Continue to develop wells and pumping infrastructure to respond for the need to supplement flows in the short-term.
- ✓ Continue to remove non-native riparian vegetation.
- ✓ Restore natural channels to provide better riparian habitat.

*Net Depletions are calculated by comparing to historic, pre-fish operations

Technical Addendum to the:

Carlsbad Project Water Operations and Water Supply Conservation Environmental Impact Statement

Roswell Artesian Basin Ground Water Model Technical Report

January 2006

Prepared by Hydrosphere Resource Consultants, Inc.

HYDROSPHERE
Resource Consultants

1.0 INTRODUCTION

Modeling of groundwater in the Roswell Artesian Basin was performed for support of NEPA alternatives impact analysis. This document provides a description of that modeling effort, focusing on:

- Identification and description of the numerical model used in the analysis
- Key modeling assumptions for both the baseline model, as well as the Carlsbad Project water acquisition option that involved both retirement of groundwater rights in the Roswell basin and development of a well field to augment Pecos River flows, and
- Resource indicators evaluated.

For additional information about the Roswell Artesian Basin Groundwater Model (RABGW) refer to the Roswell Artesian Basin Groundwater Model Documentation (Hydrosphere, 2003).

2.0 RABGW MODEL

For the NEPA alternatives impact analysis, the 2004 release of the S. S. Papadopolus & Associates (SSPA) historical (1900-2001) RABGW model was the starting point for developing the 60-year model used for NEPA scenarios. The RABGW model was developed in MODFLOW, the general groundwater modeling code developed by the USGS.

The RABGW model has its origin in the work of Ms. Amy Lewis, who spent several years (including work on her MS thesis at New Mexico Tech) compiling Roswell basin hydrogeologic data and information and working on the model. In 1995, working for DB Stephens & Associates, Lewis published a “Comprehensive Review and Model of the Hydrogeology of the Roswell Basin” (DBS&A, 1995). Known as the “Lewis Model” by the Office of the State Engineer (OSE) employees, Ms. Lewis’ product was a two-layer MODFLOW-based model that simulated flow in both the shallow alluvial and the deep artesian aquifer for the time period between 1967 and 1990. Since that time, Keyes (2001) of the OSE enhanced the Lewis model by refining the calibration, modifying recharge sources boundary conditions, and compiling historic pumping files all the way back to 1900. Most recently, the SEO contracted with SSPA to refine and improve the model further by adding a third layer that represents the confining bed between the shallow and deep aquifers, improving the treatment of evapotranspiration, and extending the end of the simulation period from 1990 to 2001.

3.0 MODELING ASSUMPTIONS FOR IMPACT ANALYSIS

The NEPA alternatives analyses for the Carlsbad Operations EIS involves numerous assumptions and adaptations from the historical model. The overarching assumption is that conditions in the future are best represented by current conditions in the Roswell Basin, as represented by the period from 1990 through 2000. With this global assumption understood, one can begin to identify and develop particular assumptions required to implement the global assumption.

Particular assumptions adopted include:

- A 60-year simulation period, with the historical hydrology from 1940 through 2000 used to provide the hydrological inputs. This assumption was also made for the RiverWare model which the RABGW model is linked to.
- To honor the global assumption that the 1990s level of development in the basin are representative of expected future conditions, adjustments to the historical evapotranspiration (ETS), river (RIV), and well (WEL) input files were made as described in detail in separate sections below.
- Using January 1, 2000 modeled heads as an initial condition

As noted in the second bullet above, several changes had to be made to the historical model inputs for NEPA use. The existing MODFLOW2000 input files had to be modified to represent the 60-year time period. The hydrologic conditions from the time period 1/1/1940 to 12/31/1999 were chosen, and the MODFLOW2000 input files DIS, RCH, ETS, DRN, OC, WEL, and RIV were modified to represent this time period. Additionally, the January 1, 2000 heads were extracted from the historical model output and the BAS file was modified to use them as initial head conditions for the 60-year NEPA model.

3.1 ETS Input File Changes

Assumptions on how to treat evapotranspiration in MODFLOW2000 are addressed in the ETS input file. As described above, one exception related to the historical hydrology inputs is that the evapotranspiriation (ET) represented in the historical calibration model will not be used. Prior to 1950 in the SSPA historical model a multiplier was used to properly simulate long-term changes in the amount and area of groundwater ET. During that period, there was a great deal of ponding of water from flowing artesian wells which led to greatly enhanced ET compared to current conditions. To account for this fact in the historical calibration model, SSPA (2003) applied an ET enhancement factor to the model. This magnitude of ET has not occurred for several decades, nor is it ever expected to occur again. Given that the NEPA 60-year model scenarios were to be representative of current and proposed future conditions, the ET multipliers for the 1940 to 1950 time period were removed to be consistent with post-1950 conditions.

3.2 RIV Input File Changes

In the RABGW model, groundwater interactions with the Pecos River (including McMillan and Brantley reservoirs) are addressed in MODFLOW's RIV input file. The historical RABGW model had a monthly varying Brantley stage from 1/1/1989 when Brantley came online through 9/30/2001. The RIV file needed to be changed such that Brantley was operated for the entire 60-year simulation to be representative of the current and future scenario conditions. A sensitivity analysis was done to determine the most appropriate method for extrapolating Brantley stage for the 60 year simulation time period. Four separate model runs were made for the 1989-2001 time period using four different approaches for treating the Brantley stage:

- the original monthly stage values,
- a yearly average stage,
- a monthly average stage (i.e. all 13 years Jan, Feb, etc. values were averaged), and
- an overall average stage.

As the Acme to Artesia baseflows are the primary resource indicator for the NEPA analysis, the difference in baseflows was used to determine which approach of these four approaches to simulating Brantley stage was best. Figure 1 shows the resultant baseflows for the four approaches. Table 1 is a summary of the average difference between the baseflows for the three proposed methods and the actual monthly varying baseflows. All three scenarios had an average difference in baseflows of less than 3 acre-feet/year. Given these results, the overall average stage was chosen and implemented in the NEPA 60-year model due to its simplicity and the lack of model sensitivity.

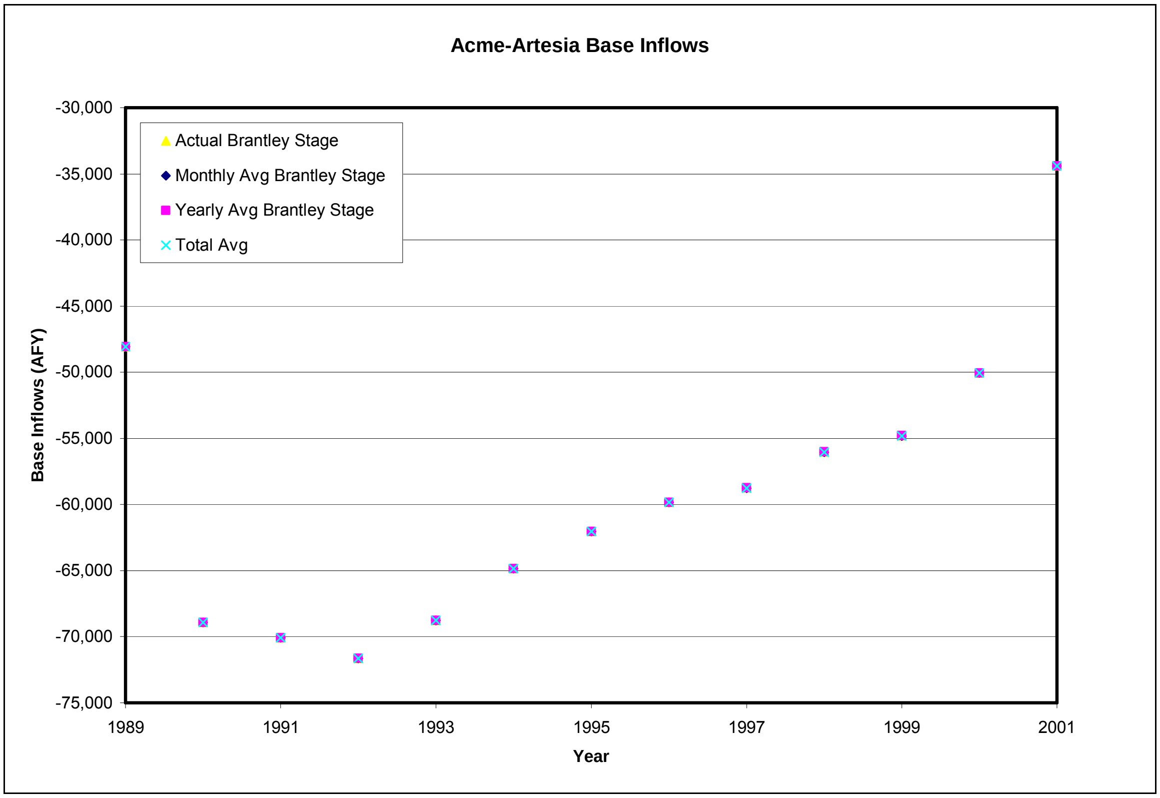


Figure 1. Annual base inflows for Brantley stage sensitivity analysis.

Table 1. Average annual difference in computed base inflows for Brantley stage sensitivity analysis; each column compares baseflows computed using actual monthly stage to stage computed as average monthly, average annual, and overall total average over 12-yr period of record.

Average Difference in Base Inflows (AFY)		
(Actual-Monthly)	(Actual-Yearly)	(Actual-Total)
2.90	0.02	2.82

3.3 WEL Input File Changes

In MODFLOW2000, well pumping is specified through the WEL input file. Pumping in the Roswell Basin is the key anthropogenic stress to the hydrological system, and is also one of the model inputs that may experience perturbations in future management alternatives considered in the EIS.

3.3.1 Historical Pumping

Historical pumping in the Lewis model was compiled from available data for the 1967 through 1990 period. Complete metered data on well pumping was only available after 1966. The Keyes model expanded the historical pumping data back to 1900. The historic annual pumping rates prior to 1966 were estimated from information in Mower (1960). In the Keyes model, annual pumping was simulated from 1900 through 1929, after which the model became seasonal with six-month stress periods as in the Lewis model. The irrigation season six-month stress period includes April 1 through September 30 and is sometimes referred to with the word “summer”. The non-irrigation season runs from October 1 to the end of March and was also sometimes referred to as the “winter” season. Pre-1967 simulated seasonal pumping percentages for the shallow aquifer were distributed to 98.7% in the summer and 1.3% in the winter, and percentages for the artesian aquifer were distributed to 95.8% in the summer and 4.2% in the winter. The estimated historical pumping was later updated by the SEO for the period 1989 to 1998 and by SSPA with data provided by the SEO for the period 1990 to 2001. The SSPA enhancements also included applying pre-1930 pumping to the summer 6-month stress period. Figure 2 shows the estimated annual historical pumping in the basin from 1900 through 2000 as simulated in the RABGW model.

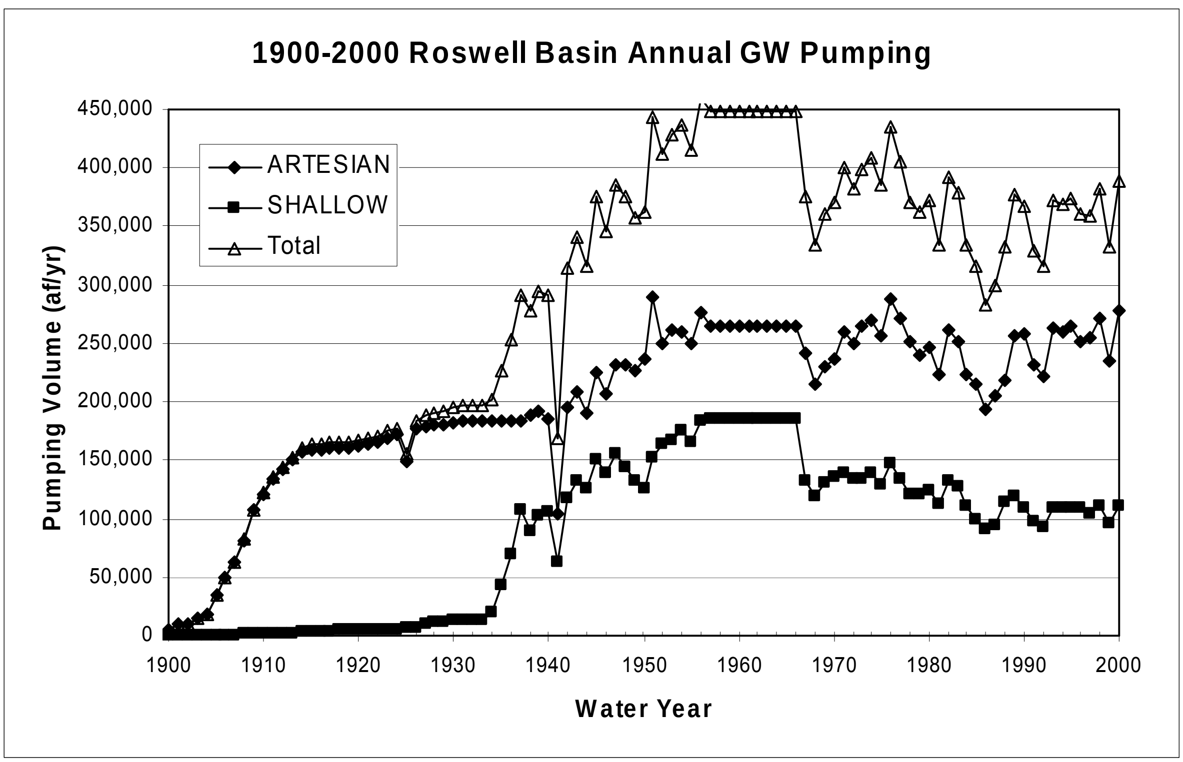


Figure 2. Estimated historical pumping from the Roswell Basin aquifers.

3.3.2 Return Flows

Annual return flows were computed as described by Keyes (2001) using the same method originally employed in the Lewis model: 33% of the total irrigation pumping in any given cell is returned to the uppermost active layer. Return flows from surface water irrigation is distributed only to lands irrigated with surface water (e.g., Hagerman Irrigation Company lands; see p. 5-42 and Fig. 5-23 in DBS&A, 1995). Return flows were simulated as uniformly returning at the same rate for both summer and winter seasons.

3.3.3 NEPA Baseline Pumping

For the NEPA analyses, EIS alternatives were simulated for a 60-year simulation period, with most hydrological inputs taken from the 1940 though 2000 historical record and initial conditions based on January 2001 observations. However, pumping from the Roswell basin aquifers exhibited significant evolution of that historical period (Figure 2), and the historical pumping record is not anticipated to reflect future pumping conditions in the basin. For example, the period between 1900 and the mid-1970s saw explosive growth in pumping from an initial value of near-zero to its maximum historical values on the order of 450,000 af/year during the drought periods of the 1950s and 1970s.

The 60-year baseline pumping was developed based on the guiding principle that the most recent (1991 through current) conditions are most representative of expected future conditions. As illustrated in Figures 3 and 4, the 60-year baseline pumping is changed from the historic such that:

- The pre-1967 artesian pumping is based on the correlation between post-1967 pumping and precipitation (Fig. 3). This is due to the fact that pumping prior to 1967 was inferred from ancillary data (as there was no metering of wells), and that total pumping in the basin was still on a growth trajectory during the period from 1940 through the 1950s.
- The shallow pumping is based on the correlation between 1991-2000 artesian and shallow pumping (Fig. 4), due to the fact that shallow pumping in this period was reduced in conjunction with water rights retirement efforts by Pecos Valley Artesian Conservancy District (PVACD) and the New Mexico Interstate Stream Commission (NMISC) in the late-1980s and early-1990s.

From the regressed lines associated with these correlations, we can develop a new time series of total pumping for the 60-yr baseline period; Figure 5 shows the total baseline pumping developed using this approach compared to the estimated historical pumping in the basin.

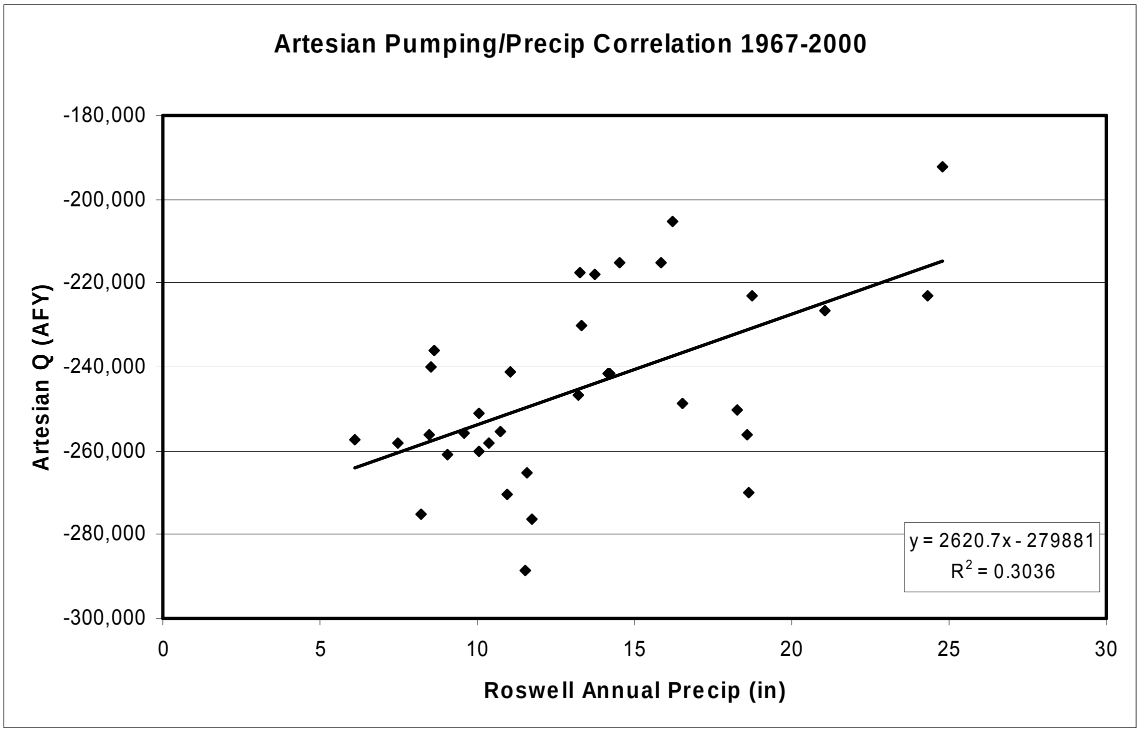


Figure 3. Correlation between post-1967 artesian pumping and precipitation.

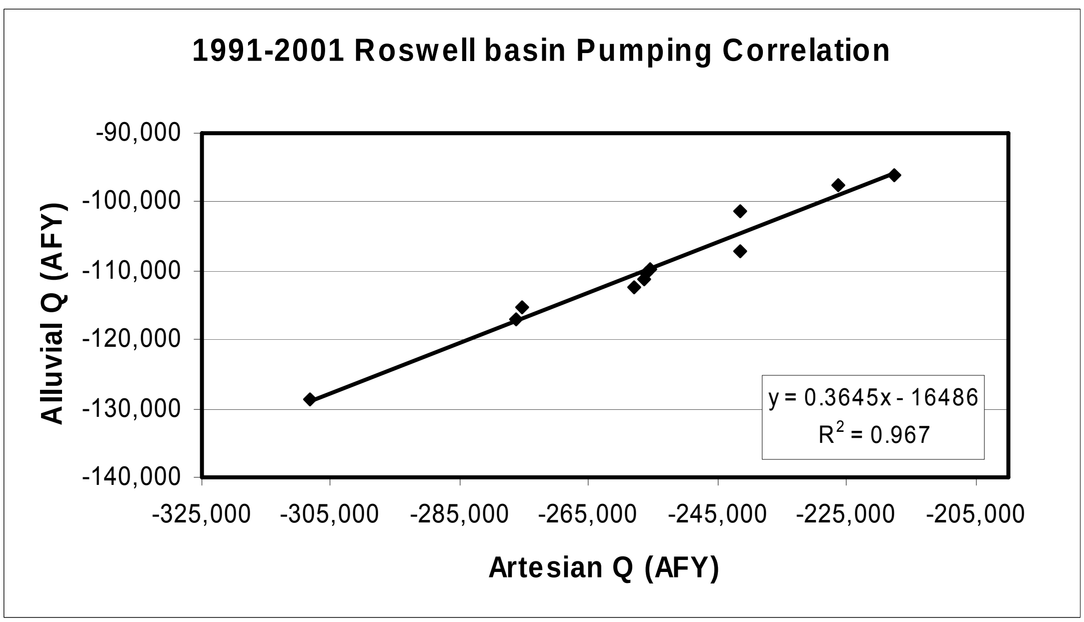


Figure 4. Correlation between 1991-2000 artesian and shallow pumping.

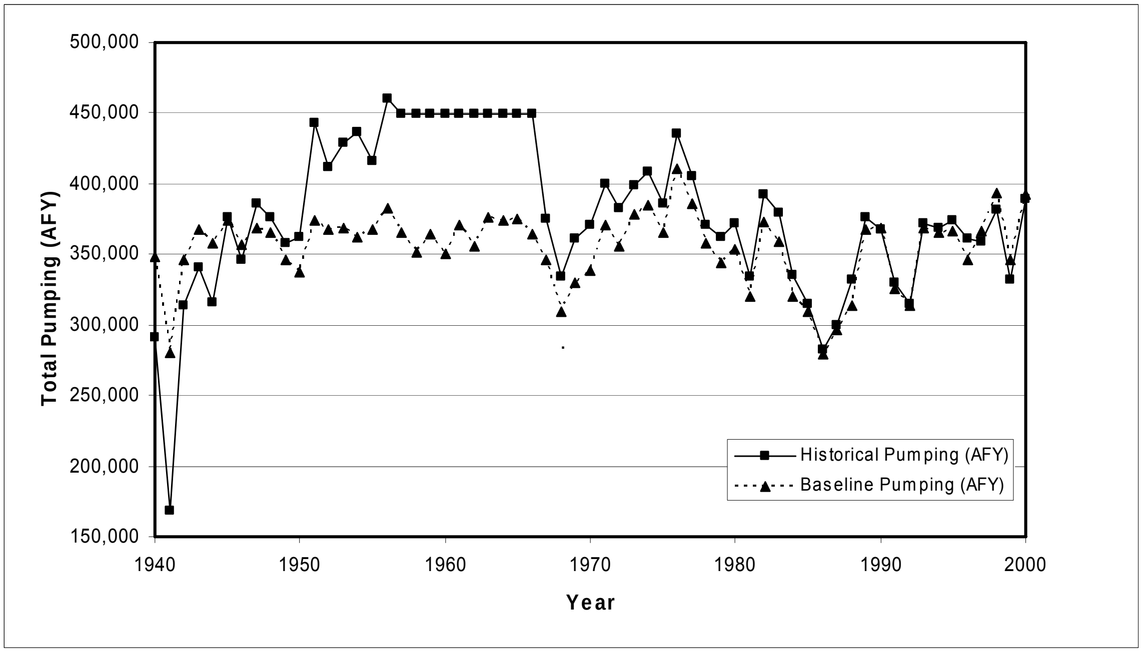


Figure 5. Total baseline and historical pumping for 60 year period.

To implement the basin-wide pumping changes to each grid cell in the model domain, the estimated historical pumping in each cell is adjusted using a time-varying scaling factor, S_b. The scaling factor is computed for each year as the ratio of the total pumping volume in the future baseline case, $V_{baseline}$, to the historical pumping volume, $V_{historic}$:

$$S_b = \left[\frac{V_{baseline}}{V_{historic}} \right] \qquad \text{(Eq. 1)}$$

Thus the total pumping for each year in the baseline model is simply S_b times $V_{historic}$, and the pumping in each grid cell is:

$$Q_{pump}^{baseline} = Q_{pump}^{historic} S_b \qquad \text{(Eq. 2)}$$

Return flows are also adjusted based on a scaling constant. The new return flows are applied only to existing return flow cells. All return flows are applied in the uppermost active model layer.

This pumping baseline was applied to all EIS alternatives, as groundwater operations were specified to be the same across all alternative. Only for the CPWA Augmentation Well Field Option did simulated pumping deviate from this baseline. In that case, pumping was adjusted at the locations of the proposed well fields, with a pumping schedule for the well field dictated by the RiverWare model-estimated depletions associated with bypass operations to meet the flow targets for each alternative (see next section).

3.3.4 NEPA CPWA Well Field Alternatives Pumping

The Carlsbad Project water acquisition (CPWA) well field option considered changes in pumping associated with water rights retirement and pumping to augment Pecos River flows ("augmentation pumping") and thus offset depletions caused by Sumner bypasses to meet flow targets. The modeled CPWA well field operations described here were implemented with the Acme Constant and Taiban Constant alternatives. Pumping associated with these future scenarios was developed using the 60-year baseline pumping distribution and multipliers calculated (similarly to Eqn. 1) from augmentation pumping and water rights retirement spreadsheets. For example, if 10% of the irrigated land in the basin is subject to retirement, then a pumping multiplier of 0.9 could be applied uniformly across the basin.

The particular water rights retirement and augmentation pumping scheme involved in the CPWA well field scenarios included:

- *the retirement of 10,000 acre-feet of consumptive use retirement in PVACD, with 73% of the acres irrigated by the deep artesian aquifer and 27% of the retired acreage irrigated by pumping from the shallow alluvial aquifer*. Water Rights Retirement was applied uniformly to all existing pumping and return flow cells (except Western Boundary Recharge cells, as this component of recharge is treated through the WEL file).
- *the well fields were assumed to have an annual pumping capacity of 12,100 AF/year or 33.14 AF/day. The Pecos River RiverWare model was used to compute the initial pumping amounts (see p. C-4 of the Offset Modeling Technical Appendix)*. Specific locations were identified for augmentation pumping from the proposed Seven Rivers and Buffalo Valley well fields, and direct adjustments to the pumping input file were applied to these specific locations. No return flows were applied from augmentation pumping. Figure 6 shows the augmentation pumping time series used for modeling the CPWA well field options with alternatives.

The decreased pumping resulting from the water rights retirement is used to develop a net change in pumping from the baseline. These values are then utilized in conjunction with the baseline pumping and multipliers to scale prescribed pumping and return flows in the model using a time-varying scaling factor, S_{retire}. The scaling factor is computed for each year as the ratio of the total pumping volume in the future for the retirement case, V_{retire}, to the historical pumping volume, $V_{baseline}$:

$$S_{retire} = \left[\frac{V_{retire}}{V_{baseline}} \right] \qquad \text{(Eq. 3)}$$

Thus the total pumping for each year in the baseline model is simply S_{retire} times $V_{baseline}$, and the pumping in each grid cell is:

$$Q_{pump}^{retire} = Q_{pump}^{baseline} S_{retire} \qquad \text{(Eq. 2)}$$

Return flows are also adjusted based on a scaling constant. The new return flows are applied only to existing return flow cells. All return flows are applied in the uppermost active model layer.

This results in a new water rights retirement - augmentation well field WEL input file for the RABGW MODFLOW model. The initial monthly augmentation pumping amounts computed using the Pecos River RiverWare model were put into units of ft^3/day and added to the water rights retirement well input file as 10 wells in the location of the proposed well field with evenly distributed pumping. Figure 7 shows the historical pumping together with baseline and action-alternative pumping for these scenarios.

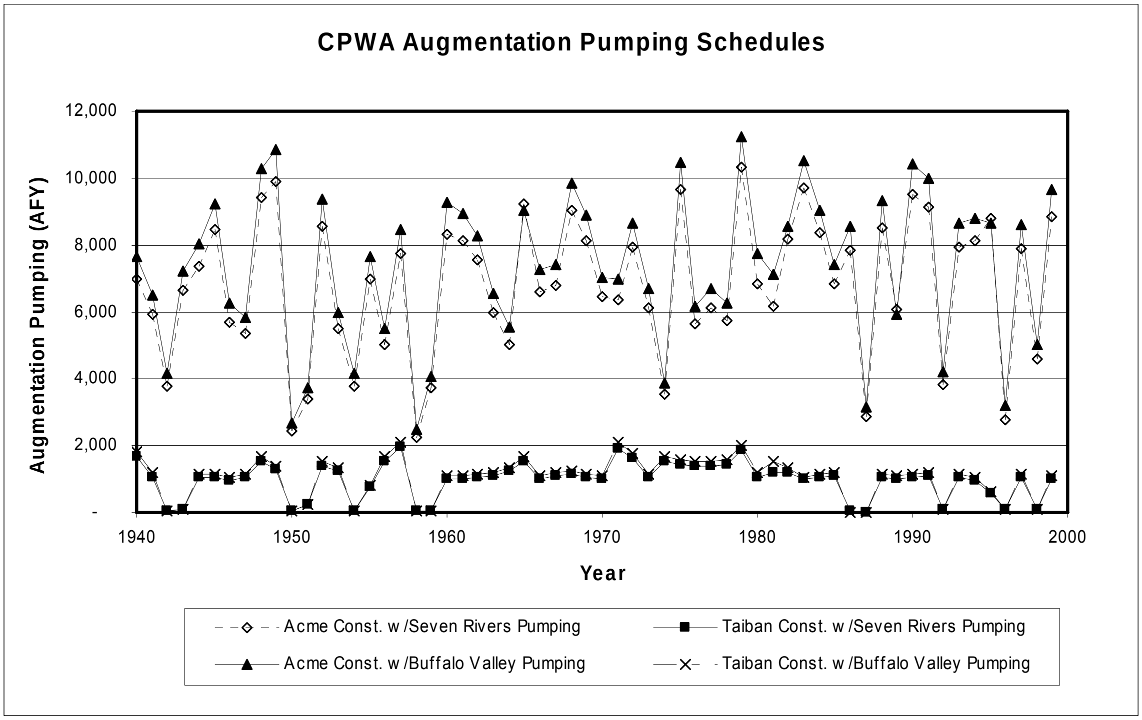


Figure 6. Augmentation pumping schedules for the CPWA well field scenarios.

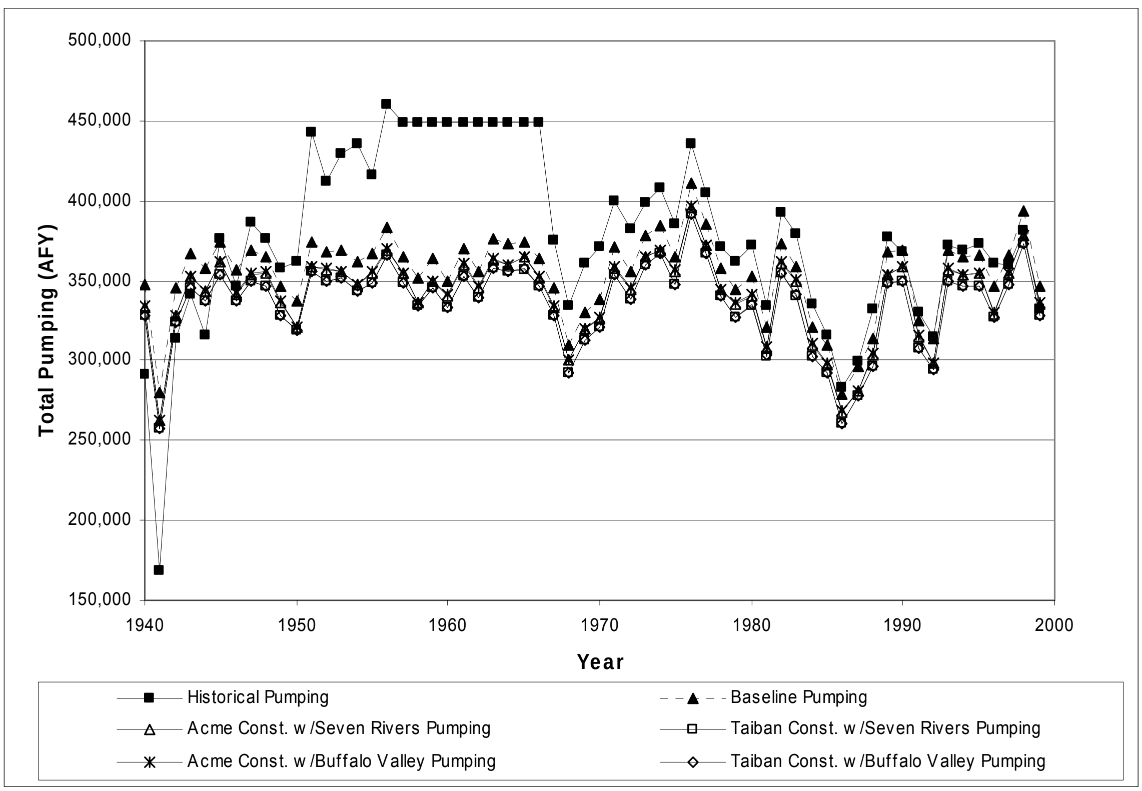


Figure 7. Total pumping for the historical, baseline, and CPWA well field scenarios.

4.0 RESOURCE INDICATORS FOR IMPACT ANALYSIS

Two resource indicators were employed to assess impacts to the basin from the EIS alternatives, aquifer storage and base inflows to the Pecos River**.**

4.1 Aquifer Storage

While well hydrographs can provide insight into the impacts of pumping changes in the basin on the water elevations at a few selected locations, a broader measure of the impact to the aquifers resulting from changes in the pumping regime is the aquifer storage. Figure 8 shows the aquifer storage for the shallow alluvial and deep artesian aquifers for the baseline and CPWA well field scenarios.

4.2 Base Inflows to the Pecos River

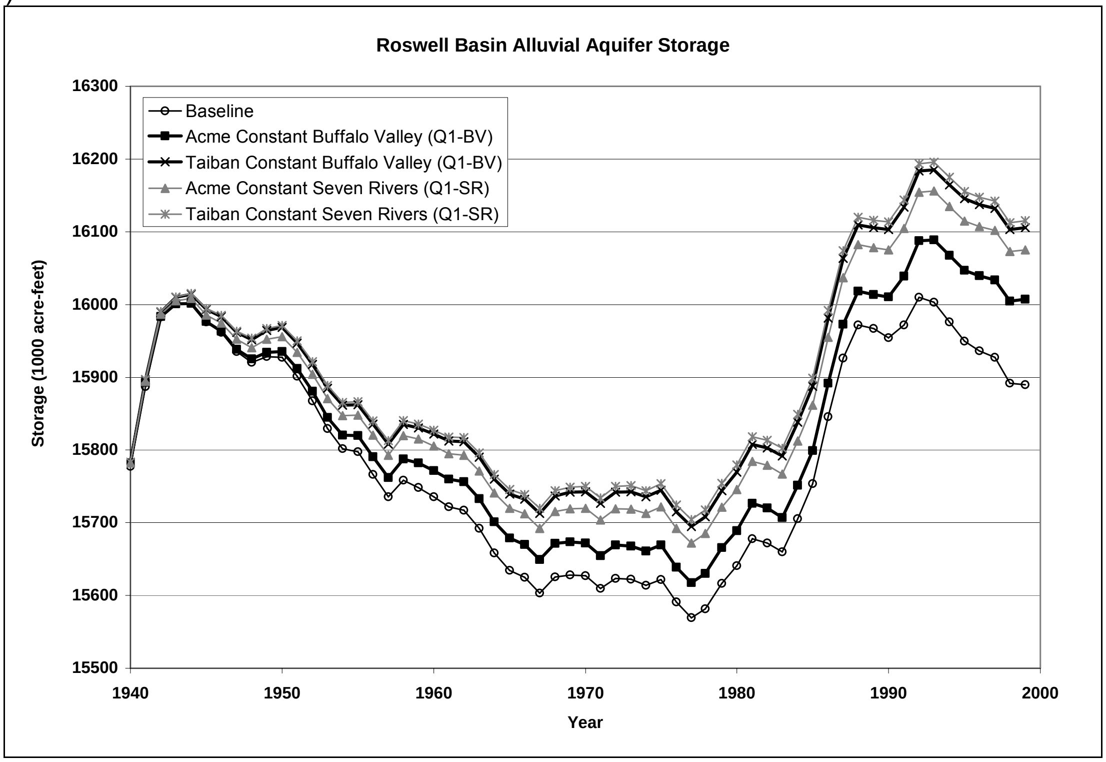
The base inflows to the river for the Acme to Artesia reach represent one of the key performance indicators of impacts of operational changes in Roswell Basin pumping on the system. Based on historical gage flow records, the Acme to Artesia reach has consistently experienced baseflow gains over the period of record, although it has varied significantly over the years as described in the next paragraph. The Artesia to Brantley reach, on the other hand, exhibits interannual variability between gaining and losing conditions (generally in the range between 6,000 af/yr loss and 500 af/yr gain). Thus, it is the Acme to Artesia reach that was selected as the resource indicator of interest.

To illustrate the importance of the Acme to Artesia baseflow resource indicator, note that under predevelopment conditions, base inflows to the river approached 100,000 af annually, and that groundwater pumping has reduced annual amounts to values on the order of 20,000 to 30,000 af per year (Fig. 9).

For the CPWA Roswell Basin groundwater option, reductions in groundwater pumping associated with water rights retirement will accrue to the river (as increased base inflows) over time, and those increased base inflows will be captured in Brantley Reservoir. Conversely, the augmentation well field pumping associated with this potion will reduce base inflows to the Pecos. Because the amount of consumptive-use retirement exceeds the average CPWA well field pumping, there will be a net increase in baseflows under this CPWA option. This is clearly illustrated in Figure 10, which shows the time series of annual base inflows for the baseline and CPWA well field scenarios. Note that in a permutations of this CPWA option, Acme to Artesia baseflows to the river increase over the baseline. The Acme Constant – Buffalo Valley well field permutation stands apart from the other permutations for this CPWA option, due the fact that the Acme Constant alternative requires greater augmentation pumping (Figure 6) in conjunction with the fact that the Buffalo Valley well field is located immediately adjacent to the Acme-Artesia reach (whereas the Seven Rivers well field is located immediately adjacent to Brantley below Artesia).

Finally, given CID's overall efficiency and the fact that return flows from CID enter the river below Carlsbad, nearly 50% of this net increase in base inflows (as well as increases in river flows due to the augmentation well field pumping) above Brantley can ultimately be realized as Pecos Compact stateline deliveries.

A.)



B.)

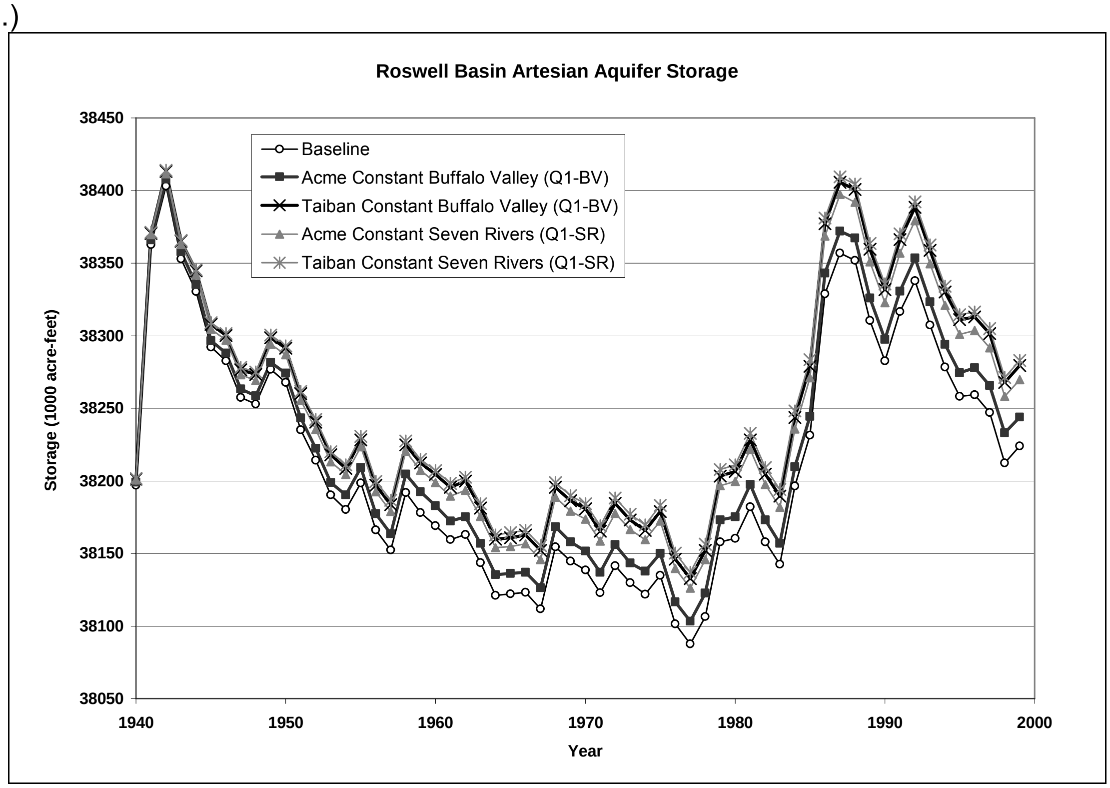
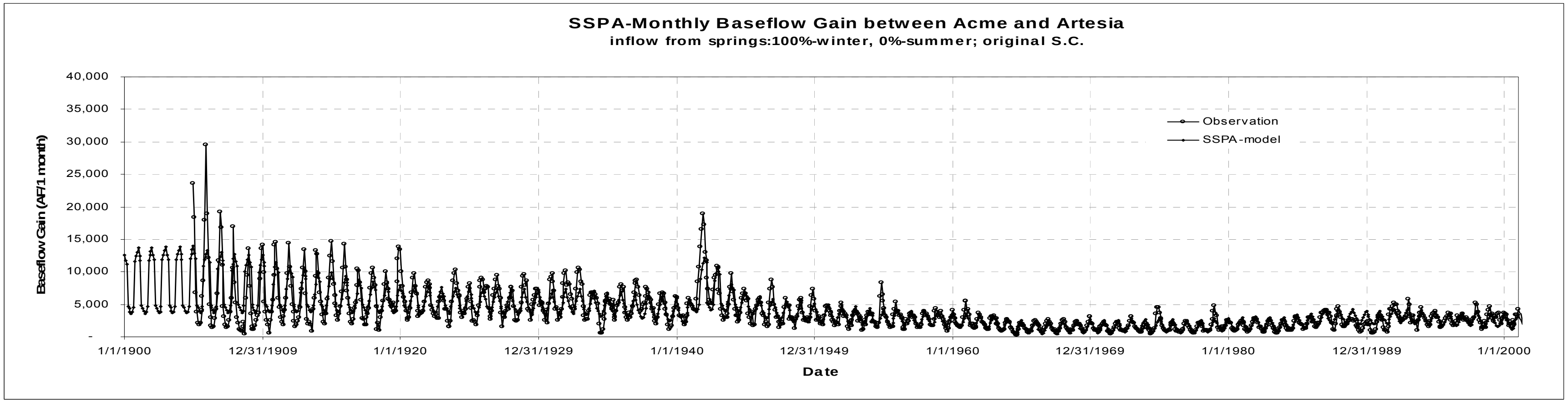


Figure 8. Storage for the Baseline and CPWA scenarios for the A.) Alluvial and B.) Artesian aquifers.

A.)



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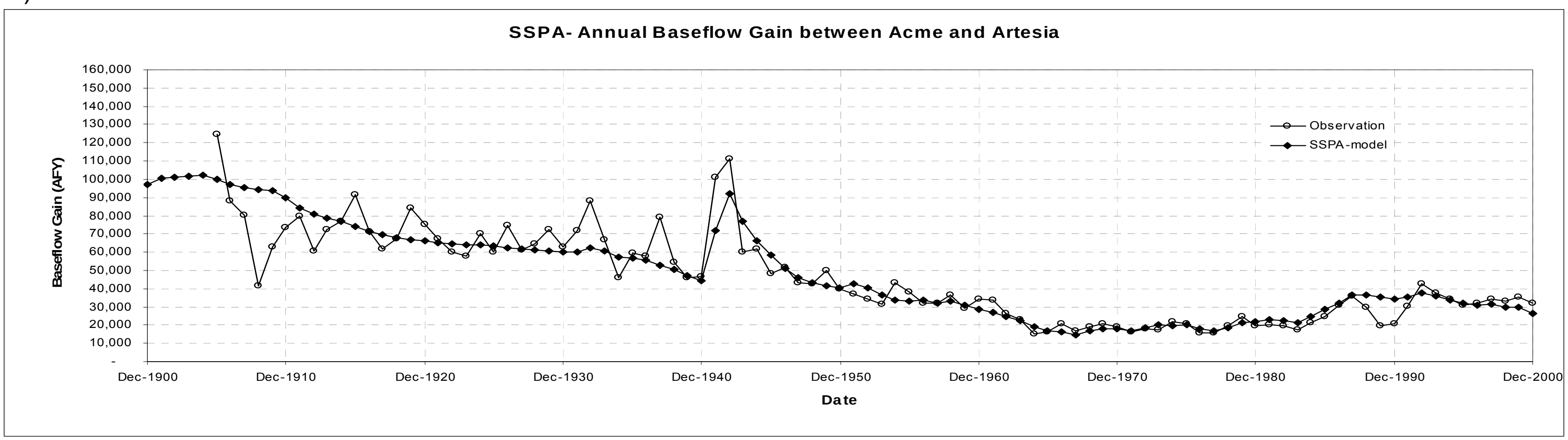

Figure 9. Observed and computed baseflow gain A) monthly and B) annual (from SSPA, 2003)

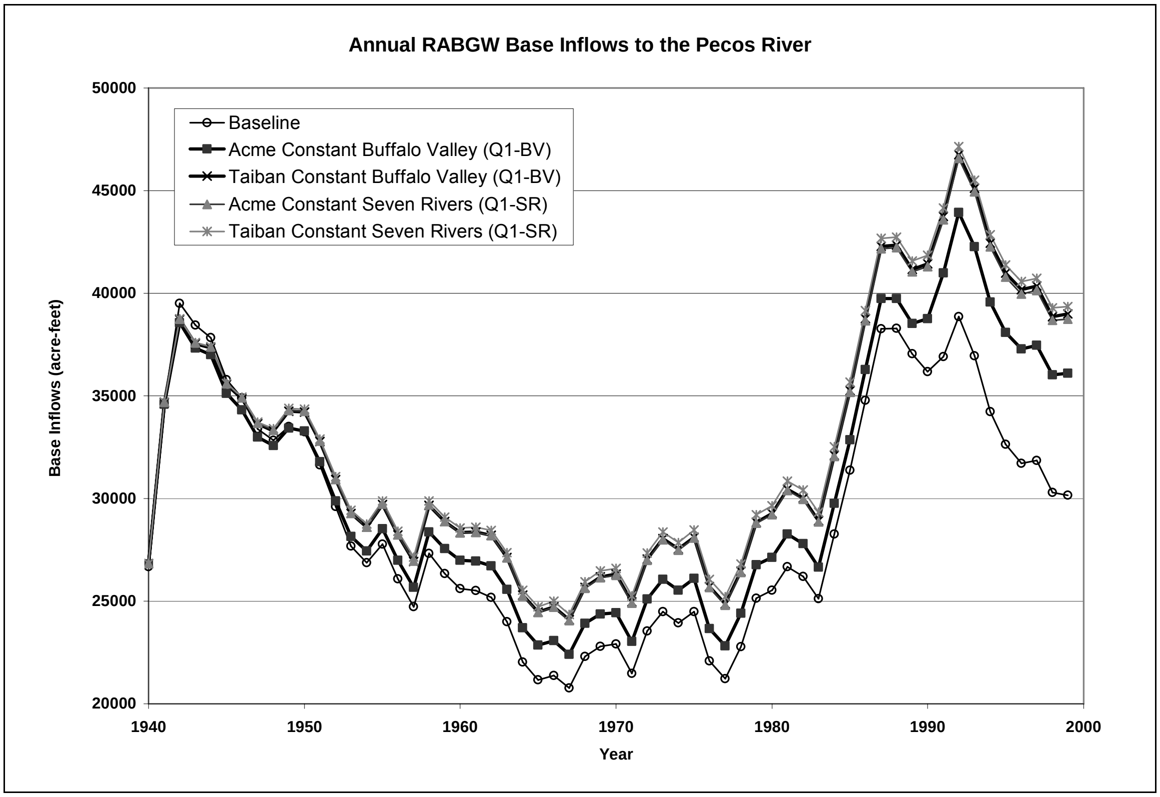

Figure 10. Annual base inflows for the Baseline and CPWA scenarios.

5.0 SUMMARY AND CONCLUSIONS

This document summarizes the groundwater modeling approach, assumptions, and results for evaluating the impacts of the EIS alternatives on groundwater resources in the Roswell Basin. None of the alternatives contemplated changes in groundwater pumping operations in the Roswell Basin, with the exception of the CPWA well field option that involved both retirement of groundwater rights, as well as development of a well field to pump groundwater to the river to help offset depletions that results from re-operations associated with the alternatives. The modeling results show that both aquifer levels and baseflows to the Pecos River increase for the CPWA well field option compared to the baseline.

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Technical Addendum to the:
Carlsbad Project Water Operations and Water Supply Conservation Environmental Impact Statement
Analysis of Intermittency

January 2006

Prepared by Hydrosphere Resource Consultants, Inc.

HYDROSPHERE
Resource Consultants

1.0 INTRODUCTION

This memorandum summarizes findings regarding intermittency trends and confidence interval calculations with respect to RiverWare model predicted and United States Geological Survey (USGS) actual gage flow. A summary of the calculations performed and an overview of the results are provided.

RiverWare model predicted or *model flow* refers to modeled river flow as output from the RiverWare model, which consists of daily model predicted values of Pecos River flow from January 1940 to December 1999. *USGS actual gage* or *gage flow* refers to stream flow data obtained from the USGS website for the relevant gage. Within this memorandum, the following gages are discussed:

- Acme gage, located along the Pecos River near river mile (RM) 600, approximately 106 miles downstream from Sumner Dam and approximately 26 river miles below the end of the Pecos Bluntnose Shiner (PBNS) upper critical habitat.
- Dunlap gage, located at RM 638.9, approximately 28 miles above the end of the upper critical habitat.

This memorandum includes descriptions of major tasks in three sections:

- Acme Gage
    - Confidence Intervals
    - Probability of Intermittency
- Dunlap Gage
    - Confidence Intervals
    - Probability of Flow Range
- Intermittency Trends by Hydrologic Season
    - Acme Intermittency
    - Length of Acme Intermittency

2.0 ACME GAGE

This section summarizes findings regarding confidence intervals with respect to RiverWare model predicted flow at Acme gage for the historical (calibration) model. Also, residual distributions are applied to estimate the expected probability of flow intermittency at the Acme gage.

This summary includes descriptions of two major tasks:

- Section 2.1 Confidence Intervals
    - Confidence interval calculations using the original model, gage, and residual data, and assuming a normal distribution.
    - A check of the above method using a random number generator and lookup table. This synthetically generated data set was then examined statistically and confidence intervals were calculated.
    - Confidence interval calculations using the original model, gage, and residual data, and assuming a lognormal distribution.
- Section 2.2 Probability of Intermittency
    - Probability of intermittency calculations.

2.1 Confidence Intervals

When dealing with “real” data sets, a statistical analysis including calculation of confidence intervals can be useful in giving an estimated range of values which is likely to include the unknown parameter, based on historical data. The width of the confidence interval gives an indication of how certain you are about the unknown parameter. Confidence intervals may be calculated at different percentage levels, the most common being percentage being 95% confidence.

2.1.1 Basic Statistics and Confidence Intervals (assuming a normal distribution of data)

RiverWare model predicted and USGS gage flow data from the Acme gage were used to calculate confidence intervals of model residuals. The model residual is defined as the model flow minus the gage flow; a negative residual corresponds to a case where the gage flow was larger than the model flow.

Basic statistics for residuals were calculated for defined modeled flow ranges for the Acme gage (for bins of 0-4, 4-8, 8-16, 16-25, 25-35, 30-40, 35-45, and 45-60 cfs). The statistics included total number of data points (N), sample mean (x), variance (σ^2), and standard deviation (σ).

Confidence intervals were calculated based on the assumption that the residuals have a normal distribution. Two different approaches, the Gaussian and Student-t, were used.[13] Results from the Student-t approach are presented, since both methods produced similar results with the large sample size. *Table 1* summarizes the statistics of each flow range and associated confidence interval that was calculated.

The following procedure was used (from Moore and McCabe, 2003; Ang and Tang, 1975):

- The original data (model flow, gage flow, and residual) was separated into bins based on model flow.
- Basic residual statistics (N, x, σ^2, and σ) were calculated for each bin.
- The appropriate t-critical value (t*), based on the desired level of confidence, was looked up in a table.
- The confidence interval for the estimated mean residual was calculated using the following equation:

$$CI = \left(\sigma \big/ \sqrt{N} \right) \times t^* \qquad \textit{Equation 1}$$

Table 1. Summary statistics and confidence intervals of residuals calculated for modeled flow ranges at the Acme gage. Negative values indicate that gage flows are higher than model flows.

Modeled Flow Range (cfs)	Total number of data points, *N*	Mean Residual, *x* (cfs)	Variance, σ^2 (cfs^2)	Standard Deviation, σ (cfs)	95% Confidence Interval (+/- cfs)	99% Confidence Interval (+/- cfs)
0-4	3,503	-11.2	825.8	28.7	0.98	1.31
4-8	2,136	-8.6	780.9	27.9	1.22	1.63
8-16	3,854	-5.6	707.4	26.6	0.87	1.16
16-25	2,663	-4.4	654.5	25.6	1.00	1.34
25-35	1,716	-3.8	951.8	30.9	1.51	2.01
30-40	1,369	-1.3	757.3	27.5	1.50	2.01
35-45	1,098	-2.1	822.6	28.7	1.75	2.34
45-60	997	-8.1	1451.7	38.1	2.44	3.26

[13] As a general note on calculating confidence intervals, the Student-t method *must* be used when dealing with small samples (those of size 30 or below). For larger sample sizes, the Gaussian method as an approximation to the Student-t confidence interval is appropriate. The difference between the methods arises from the t-critical value which is used, or t*.

2.1.2 Synthetically Generated Residual Data Set

A data set of residuals for the 0-4 cfs modeled flow range was synthetically generated in order to perform a check of the above calculations. The following procedure was used:

- A uniform random number was generated between 1 and N. This was done N times (3,503 in this case) so that the generated data set was the same size as the original.
- The lookup function in Microsoft Excel was used to find the original residual ranking corresponding to this randomly generated number. This original residual was then added to the synthetically generated residual set until all the randomly generated numbers were expended.
- Basic statistics for this generated residual data set were calculated using the same procedure described in Section 2.1.1.

For the sake of time and efficiency, only one modeled flow range was examined. The 0-4 cfs modeled flow range was chosen because this is the most critical range to understand when evaluating modeled intermittency frequency, which is most likely to occur in this flow range. Resulting statistics and confidence intervals are very similar to that of the original data set (*Table 2*).

Table 2. Summary statistics and confidence intervals of residuals calculated for generated residual data.

Flow Range (cfs)	Total number of data points, *N*	Mean Residual (cfs)	Variance (cfs^2)	Standard Deviation, σ (cfs)	95% Confidence Interval (+/- cfs)	99% Confidence Interval (+/- cfs)
0-4	3,503	-11.5	925.5	30.4	1.04	1.39

2.1.3 Basic Statistics and Expanded Confidence Intervals (assuming a lognormal distribution of data)

Considering the possibility that the residual data may not be normally distributed, a closer inspection revealed that the data was in fact skewed to the left, and appeared to have a lognormal distribution (*Figure 1*). Generally speaking, many of the residuals fell along a “tail” to the left (negative), which corresponds to gage flow larger than model.

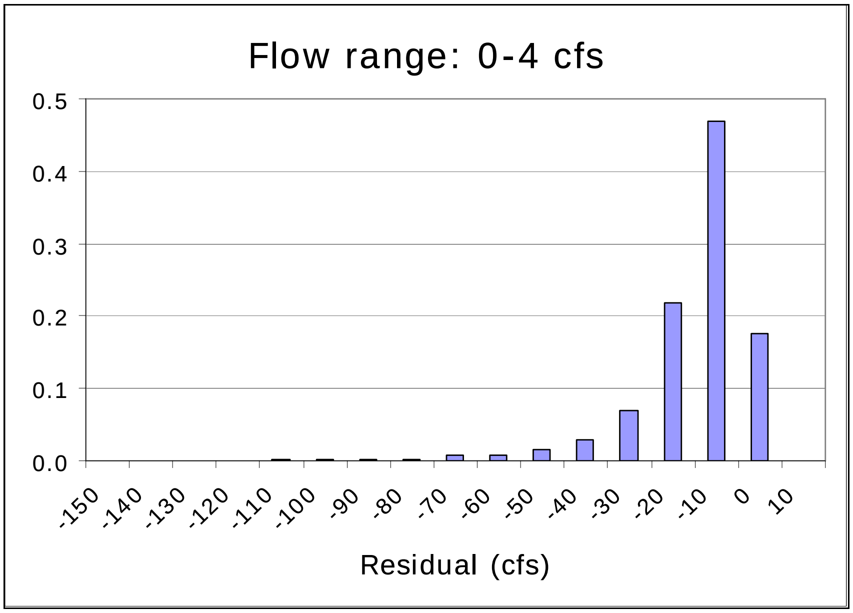


Figure 1. Histogram of model residual data illustrating the lognormal distribution which is skewed to the left. Note that not the entire graph is not shown in this figure; the actual minimum and maximum residual of the original data set were -845.7 and 4.0 cfs, respectively.

Basic statistics were calculated for the 0-4 cfs flow range. The lowest 8 residual values (0.02% of the data set) were not used in the calculations, as they were determined to be outliers. *Table 3* summarizes the statistics of the 0-4 cfs flow range. The median is higher than the mean of the data set, which typically indicates a skewed data set. The results are similar to the above analysis which assumed a normal distribution (*Table 2*), but these statistics provide a better representation of the data given the clear skewness of the distribution (Figure 1).

Table 3. Summary statistics of residuals calculated for log transformed residual data at the Acme gage, 0-4 cfs modeled flow range.

Modeled Flow Range (cfs)	Total number of data points, *N*	Mean (cfs)	Median (cfs)	Variance (cfs^2)	Standard Deviation, σ (cfs)
0-4	3,795	-10.1	-5.9	317.3	17.8

The Student-t method was used to calculate *confidence intervals* at a wide range of levels. The confidence interval at 50% confidence is +/- 1.23 cfs; at 99.9% confidence, the interval is +/- 2.92 cfs (*Table 4*). Keeping in mind that the total range of data is 837 cfs, the calculated confidence intervals are relatively small. *Figure 2* is a graphic representation of the magnitude of confidence intervals at various levels of confidence in the form of a probability distribution function (PDF) for the Confidence Interval Model. As expected, both *Table 4* and *Figure 2* show that at high levels of confidence, the corresponding confidence interval is larger than at low levels of confidence.

Table 4. Range of confidence levels and corresponding intervals for log transformed residual data in the 0-4 cfs modeled flow range.

Confidence Level (%)	10	20	30	40	50	60	70	80	90	95	99	99.9
+/- cfs	0.40	0.76	0.96	1.12	1.23	1.29	1.37	1.48	1.66	1.84	2.26	2.92

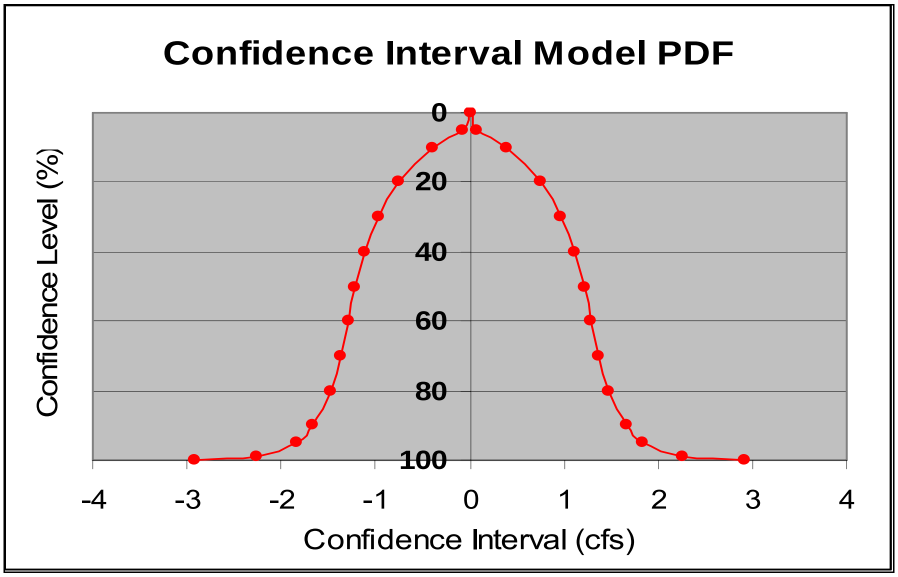


Figure 2. Probability distribution function (PDF) to graphically illustrate mean log-transformed residual confidence interval ranges at varying levels of confidence in the 0-4 cfs flow range. The y-axis corresponds to the confidence level, in %; the x-axis corresponds to the magnitude of the associated confidence interval, in cfs. For data used to create graph, see *Table 4*.

2.2 Probability of Intermittency

The probability of intermittency occurring is of particular interest since avoiding intermittency in parts of the Pecos River is crucial in maintaining the critical habitat for the PBNS. The Acme gage is located approximately 26 river miles below the end of the upper critical habitat, and it has historically shown intermittency approximately 10% of the time over its period of record. Comparing the gage records to the calibration model predicted flows provides a basis for projecting intermittencies for the future under the various EIS alternatives. In other words, there are times when the gage showed zero flow that the calibration model predicts flow, and conversely there are times when the model predicts zero flow but the gage showed flow. Thus prediction of intermittency is more complicated than simply considering model-predicted zero flows, and conditional probability approaches are required. To address this question, the raw residual data analyzed above is also directly applied to estimate the intermittency probability as described below.

2.2.1 Conditional Probability of Zero Gage Flow

Probability of intermittency was estimated based on the empirical model residuals for flow at the Acme gage using a conditional probability approach (Moore and McCabe, 2003; Ang and Tang, 1975). In essence, conditional probability theory states that the probability of some event X can be computed as the product of the probability of X given the occurrence of Y times the probability of event Y:

$$P(X) = P(X \mid Y) \times P(Y) \qquad \textit{Equation 2}$$

P(X), *P(X|Y)*, and *P(Y)* as they are used for this application are defined in the following section.

For this application, three key variables were defined:

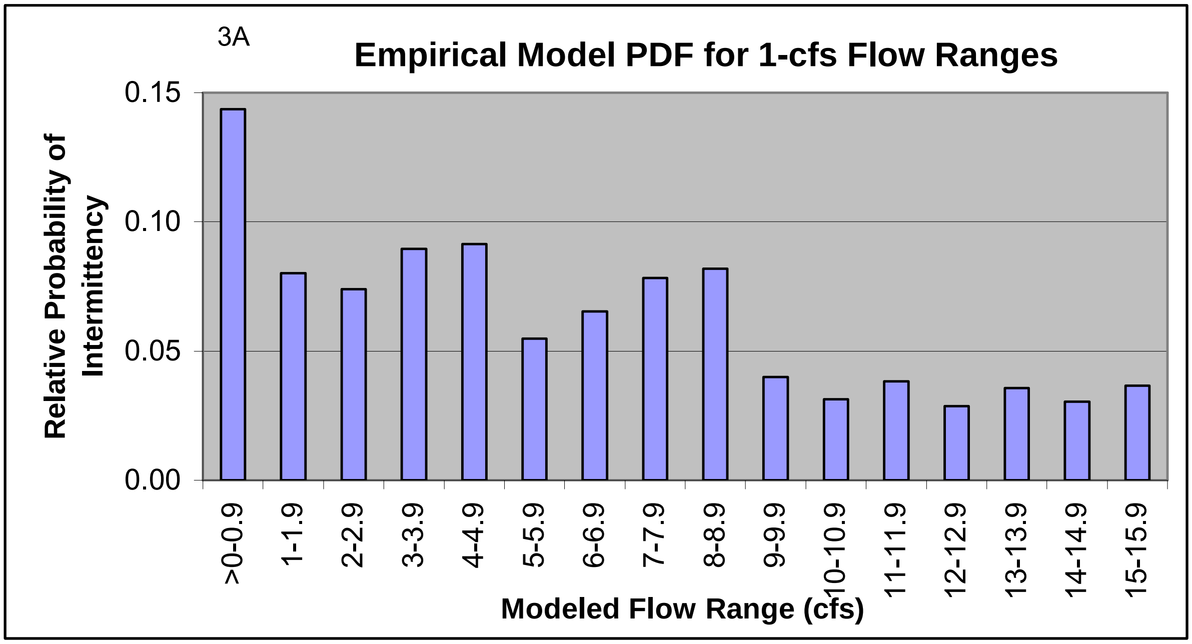
- the total number of predicted daily flows (*N*);
- the number of data points in each defined flow range (*N1*); and
- the number of times when gage flow was 0 cfs in each specified modeled flow range (*N2*).

The conditional probability of intermittency at the Acme gage given model flow within a specific range (*P2=P (X|Y)*) is calculated as *N2/N1* (*Table 5*). From these results, a PDF can be developed (*Figure 3*) that is similar to that presented for the Confidence Interval Model in *Figure 2*. This graph assumes that the probability associated with non-intermittency is one minus the conditional probability of intermittency. The graph illustrates that at lower model flow ranges, the probability of zero gage flow is higher than at higher flow ranges. The conditional probability of intermittency will approach zero as the model flow range increases, as illustrated by *Figure 3B*.

This empirical probability analysis can be used to compute the total probability of intermittency. The probability of flow within the specified range (*P1*) was calculated by *N1/N*. The conditional probability of zero gage flow within the specified range (*P2*) for each alternative is assumed to be the same as for the original Acme Gage Empirical Model, which is described in the preceding paragraph. The probability of intermittency (*P3*) can then be calculated as *P1*P2*.

Table 5. Summary of expected probability of gage flow equal to 0 cfs for various ranges of model flow. Results refer to examination of the actual residual data set. Total number of data points (*N*) is 21,914.

		Empirical Model, ACME Gage; N= 21,914				
Model Flow (cfs)	Expected Gage Flow (cfs)	*N1* Data points in the specified Model Flow range	*N2* Occurrences of Gage Flow = 0 cfs	*P1* Probability of model flow within range	*P2* Conditional Probability of gage flow =0 cfs	*P3* Probability of Intermittency given Model Flow within range
				N1 / N	*N2 / N1*	*P1 * P2*
Broader Flow Ranges:						
0	0	1227	267	0.06	0.22	0.01
>0-3.9	0	2270	445	0.10	0.20	0.02
4-7.9	0	2132	333	0.10	0.16	0.02
8-15.9	0	3854	371	0.18	0.10	0.02
16-24.9	0	2663	228	0.12	0.09	0.01
25-34.9	0	1716	163	0.08	0.09	0.01
35-44.9	0	1098	60	0.05	0.05	0.003
45-59.9	0	997	29	0.05	0.03	0.001
>60	0	5957	4	0.27	0.001	0.0002
1 cfs-Interval Flow Ranges:						
>0-0.9	0	625	165	0.03	0.26	0.01
1-1.9	0	497	92	0.02	0.19	0.004
2-2.9	0	548	85	0.03	0.16	0.004
3-3.9	0	600	103	0.03	0.17	0.005
4-4.9	0	552	105	0.03	0.19	0.005
5-5.9	0	492	63	0.02	0.13	0.003
6-6.9	0	542	75	0.02	0.14	0.003
7-7.9	0	546	90	0.02	0.16	0.004
8-8.9	0	565	94	0.03	0.17	0.004
9-9.9	0	519	46	0.02	0.09	0.002
10-10.9	0	463	36	0.02	0.08	0.002
11-11.9	0	545	44	0.02	0.08	0.002
12-12.9	0	499	33	0.02	0.07	0.002
13-13.9	0	442	41	0.02	0.09	0.002
14-14.9	0	427	35	0.02	0.08	0.002
15-15.9	0	394	42	0.02	0.11	0.002



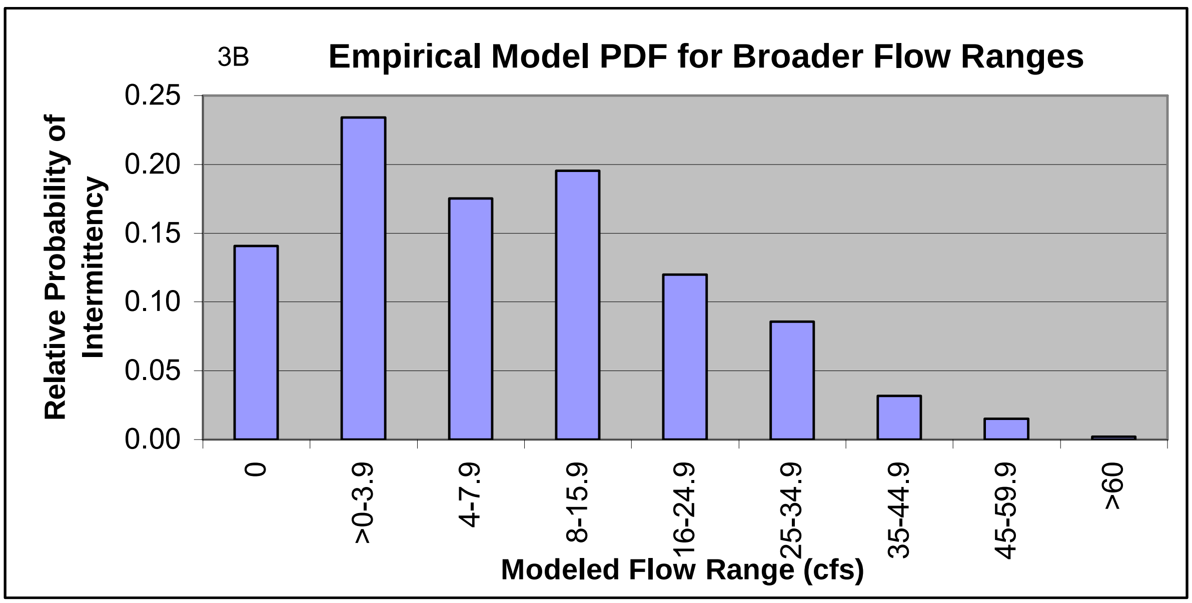


Figure 3. Empirical PDF (probability density function) to graphically illustrate intermittency probability distributed across all modeled flow ranges associated with intermittency. The y-axis corresponds to the relative probability of intermittency and the x-axis corresponds to the modeled flow range. For data used to create graphs, see *Table 5*.

2.2.2 Total Probability of Intermittency

Finally, to get the total probability of intermittency, the probability of gage flows greater than zero when the model is predicting zero flow is subtracted from *P3*:

$$P_{total}(X) = P(X \mid Y)P(Y) - P(Z \mid Y_0) \qquad \textit{Equation 3}$$

X = intermittency at gage Y = Range min < Q model < Range max
Z = Q gage > 0 cfs Y_0 = Q model = 0 cfs

The probability of non-zero gage flow (considered to be greater than 0.98 cfs based on the computed confidence interval) when model flow is equal to 0 cfs is constant for all alternatives, and was computed to be 4.2%.[14] Thus, the total probability of intermittency for each alternative was calculated as the sum of the intermittency probabilities over the individual flow range probabilities minus the probability of gage flow greater than 0 when model flow is equal to 0 cfs.

These calculations were undertaken for each of the EIS alternatives, for both the Bypass Alternatives and the Alternatives with all the Additional Water Needed (AWN) added to the river system; results are shown in *Table 6*.

2.3 Summary of Acme Gage Analysis

Basic statistics and Student-t confidence intervals were calculated for defined flow ranges based on a normal distribution of the historical model residual data for the Acme gage. A closer inspection of residual data corresponding to model flow of 0-4 cfs revealed a lognormal distribution that is skewed to the left (gage flow is more commonly larger than model flow). The range of confidence intervals for the log-transformed data ranged from +/- 0.40 to 2.92 cfs corresponding to confidence levels of 10 to 99.9 %, respectively. The intervals are relatively small for all low flow ranges examined, even when considering high levels of confidence.

[14] For the 0-4 cfs flow range, the calculated 95% confidence interval was 0.98 cfs. The probability of non-zero flow when modeled flow is zero is 4.2% as derived from the calibration model, and it is thus constant across all alternatives.

Table 6. Probability of intermittency (*P3*) for particular broader flow ranges and *Total Probability of Intermittency* for each Bypass Alternative and Alternative with all AWN added based on empirical model relationships. For a detailed description of the variables (*N*, *N1*, *P1*, *P2*, and *P3*) and how they were calculated, see text. n/c indicates that the value was not calculated here, as it was obtained from historical calibration model (both *P2* and probability of non-zero gage flow when modeled flow is zero).

		No Action w/6week; N= 21,915				No Action w/o 6week; N= 21,915			
	Model Flow (cfs)	*N1*	*P1*	*P2*	*P3*	*N1*	*P1*	*P2*	*P3*
			N1 / N	n/c	*P1 * P2*		*N1 / N*	n/c	*P1 * P2*
BYPASS ALTERNATIVES	*Broader Flow Ranges:*								
	0	193	0.01	0.22	0.002	205	0.01	0.22	0.002
	>0-3.9	651	0.03	0.20	0.006	637	0.03	0.20	0.006
	4-7.9	1513	0.07	0.16	0.011	1629	0.07	0.16	0.012
	8-15.9	2228	0.10	0.10	0.010	2191	0.10	0.10	0.010
	16-24.9	2572	0.12	0.09	0.010	2625	0.12	0.09	0.010
	25-34.9	5084	0.23	0.09	0.022	5159	0.24	0.09	0.022
	35-44.9	2440	0.11	0.05	0.006	2405	0.11	0.05	0.006
	45-59.9	1828	0.08	0.03	0.002	1805	0.08	0.03	0.002
	>60	5406	0.25	0.00	0.0002	5259	0.24	0.00	0.0002
	Probability of gage flow >0 cfs when mod flow =0 cfs:								
					0.042				0.042
	Cumulative Probability of Intermittency:								
					0.028				0.029
ALTERNATIVES WITH ALL AWN ADDED	*Broader Flow Ranges:*								
	0	147	0.01	0.22	0.001	158	0.01	0.22	0.002
	>0-3.9	468	0.02	0.20	0.004	489	0.02	0.20	0.004
	4-7.9	1253	0.06	0.16	0.009	1336	0.06	0.16	0.010
	8-15.9	1513	0.07	0.10	0.007	1377	0.06	0.10	0.006
	16-24.9	2868	0.13	0.09	0.011	2925	0.13	0.09	0.011
	25-34.9	1132	0.05	0.09	0.005	1165	0.05	0.09	0.005
	35-44.9	7152	0.33	0.05	0.018	7252	0.33	0.05	0.018
	45-59.9	1902	0.09	0.03	0.003	1885	0.09	0.03	0.003
	>60	5480	0.25	0.00	0.0002	5328	0.24	0.00	0.0002
	Probability of gage flow >0 cfs when mod flow =0 cfs:								
					0.042				0.042
	Cumulative Probability of Intermittency:								
					0.016				0.017

Table 6, continued.

		Pre-91 Baseline; N= 21,915				Acme Constant; N= 21,915			
	Model Flow (cfs)	*N1*	*P1*	*P2*	*P3*	*N1*	*P1*	*P2*	*P3*
			N1 / N	n/c	*P1 * P2*		*N1 / N*	n/c	*P1 * P2*
BYPASS ALTERNATIVES	*Broader Flow Ranges:*								
	0	263	0.01	0.22	0.003	147	0.01	0.22	0.001
	>0-3.9	889	0.04	0.20	0.008	367	0.02	0.20	0.003
	4-7.9	2897	0.13	0.16	0.021	691	0.03	0.16	0.005
	8-15.9	4346	0.20	0.10	0.019	1856	0.08	0.10	0.008
	16-24.9	3691	0.17	0.09	0.014	2017	0.09	0.09	0.008
	25-34.9	1603	0.07	0.09	0.007	7077	0.32	0.09	0.031
	35-44.9	982	0.04	0.05	0.002	2735	0.12	0.05	0.007
	45-59.9	1709	0.08	0.03	0.002	1840	0.08	0.03	0.002
	>60	5535	0.25	0.00	0.0002	5185	0.24	0.00	0.0002
	Probability of gage flow >0 cfs when mod flow =0 cfs:								
					0.042				0.042
	Cumulative Probability of Intermittency:								
					0.036				0.025
ALTERNATIVES WITH ALL AWN ADDED	*Broader Flow Ranges:*								
	0		0.0		0.0	0	0.00	0.22	0
	>0-3.9		0.0		0.0	2	0.00	0.20	0.00002
	4-7.9		0.0		0.0	1	0.00	0.16	0.00001
	8-15.9		0.0		0.0	3	0.00	0.10	0.00001
	16-24.9		0.0		0.0	5	0.00	0.09	0.00002
	25-34.9		0.0		0.0	2177	0.10	0.09	0.009
	35-44.9		0.0		0.0	12275	0.56	0.05	0.031
	45-59.9		0.0		0.0	1967	0.09	0.03	0.003
	>60		0.0		0.0	5485	0.25	0.00	0.0002
	Probability of gage flow >0 cfs when mod flow =0 cfs:								
					no data				0.042
	Cumulative Probability of Intermittency:								
					no data				0.001

Table 6, continued.

		Acme Variable; N= 21,915				Critical Habitat; N= 21,915			
	Model Flow (cfs)	*N1*	*P1*	*P2*	*P3*	*N1*	*P1*	*P2*	*P3*
			N1 / N	n/c	*P1 * P2*		*N1 / N*	n/c	*P1 * P2*
BYPASS ALTERNATIVES	*Broader Flow Ranges:*								
	0	150	0.01	0.22	0.001	234	0.01	0.22	0.002
	>0-3.9	460	0.02	0.20	0.004	690	0.03	0.20	0.006
	4-7.9	870	0.04	0.16	0.006	1865	0.09	0.16	0.013
	8-15.9	3042	0.14	0.10	0.013	2809	0.13	0.10	0.012
	16-24.9	2606	0.12	0.09	0.010	6278	0.29	0.09	0.025
	25-34.9	4941	0.23	0.09	0.021	1699	0.08	0.09	0.007
	35-44.9	2570	0.12	0.05	0.006	1050	0.05	0.05	0.003
	45-59.9	1928	0.09	0.03	0.003	1681	0.08	0.03	0.002
	>60	5348	0.24	0.00	0.0002	5609	0.26	0.00	0.0002
	Probability of gage flow >0 cfs when mod flow =0 cfs:								
					0.042				0.042
	Cumulative Probability of Intermittency:								
					0.025				0.030
ALTERNATIVES WITH ALL AWN ADDED	*Broader Flow Ranges:*								
	0	0	0.00	0.22	0	187	0.01	0.22	0.002
	>0-3.9	2	0.00	0.20	0.00002	498	0.02	0.20	0.004
	4-7.9	5	0.00	0.16	0.00004	1965	0.09	0.16	0.014
	8-15.9	3265	0.15	0.10	0.014	2860	0.13	0.10	0.013
	16-24.9	2738	0.12	0.09	0.011	6353	0.29	0.09	0.025
	25-34.9	1055	0.05	0.09	0.005	1696	0.08	0.09	0.007
	35-44.9	6442	0.29	0.05	0.016	1058	0.05	0.05	0.003
	45-59.9	2896	0.13	0.03	0.004	1685	0.08	0.03	0.002
	>60	5512	0.25	0.00	0.0002	5613	0.26	0.00	0.0002
	Probability of gage flow >0 cfs when mod flow =0 cfs:								
					0.042				0.042
	Cumulative Probability of Intermittency:								
					0.008				0.029

Table 6, continued.

		Taiban Constant; N= 21,915				Taiban Variable (55 cfs); N= 21,915			
	Model Flow (cfs)	*N1*	*P1*	*P2*	*P3*	*N1*	*P1*	*P2*	*P3*
			N1 / N	n/c	*P1 * P2*		*N1 / N*	n/c	*P1 * P2*
BYPASS ALTERNATIVES	*Broader Flow Ranges:*								
	0	196	0.01	0.22	0.002	137	0.01	0.22	0.001
	>0-3.9	732	0.03	0.20	0.007	489	0.02	0.20	0.004
	4-7.9	1930	0.09	0.16	0.014	910	0.04	0.16	0.006
	8-15.9	2731	0.12	0.10	0.012	3781	0.17	0.10	0.017
	16-24.9	6278	0.29	0.09	0.025	6388	0.29	0.09	0.025
	25-34.9	1698	0.08	0.09	0.007	1978	0.09	0.09	0.009
	35-44.9	1039	0.05	0.05	0.003	1075	0.05	0.05	0.003
	45-59.9	1668	0.08	0.03	0.002	1667	0.08	0.03	0.002
	>60	5643	0.26	0.00	0.0002	5490	0.25	0.00	0.0002
	Probability of gage flow >0 cfs when mod flow =0 cfs:								
					0.042				0.042
	Cumulative Probability of Intermittency:								
					0.030				0.026
ALTERNATIVES WITH ALL AWN ADDED	*Broader Flow Ranges:*								
	0	0	0.00	0.22	0	0	0.00	0.22	0
	>0-3.9	859	0.04	0.20	0.008	2	0.00	0.20	0.00002
	4-7.9	1963	0.09	0.16	0.014	5	0.00	0.16	0.00004
	8-15.9	2587	0.12	0.10	0.011	4187	0.19	0.10	0.018
	16-24.9	6434	0.29	0.09	0.025	5923	0.27	0.09	0.023
	25-34.9	1715	0.08	0.09	0.007	3252	0.15	0.09	0.014
	35-44.9	1043	0.05	0.05	0.003	1289	0.06	0.05	0.003
	45-59.9	1666	0.08	0.03	0.002	1719	0.08	0.03	0.002
	>60	5648	0.26	0.00	0.0002	5538	0.25	0.00	0.0002
	Probability of gage flow >0 cfs when mod flow =0 cfs:								
					0.042				0.042
	Cumulative Probability of Intermittency:								
					0.029				0.020

Table 6, continued.

		Taiban Variable (40 cfs); N= 21,915				Taiban Variable (45 cfs); N= 21,915			
	Model Flow (cfs)	*N1*	*P1*	*P2*	*P3*	*N1*	*P1*	*P2*	*P3*
			N1 / N	n/c	*P1 * P2*		*N1 / N*	n/c	*P1 * P2*
BYPASS ALTERNATIVES	*Broader Flow Ranges:*								
	0	187	0.01	0.22	0.002	176	0.01	0.22	0.002
	>0-3.9	597	0.03	0.20	0.005	514	0.02	0.20	0.005
	4-7.9	2055	0.09	0.16	0.015	2053	0.09	0.16	0.015
	8-15.9	2737	0.12	0.10	0.012	2807	0.13	0.10	0.012
	16-24.9	6303	0.29	0.09	0.025	6370	0.29	0.09	0.025
	25-34.9	1709	0.08	0.09	0.007	1751	0.08	0.09	0.008
	35-44.9	1043	0.05	0.05	0.003	1048	0.05	0.05	0.003
	45-59.9	1693	0.08	0.03	0.002	1609	0.07	0.03	0.002
	>60	5591	0.26	0.00	0.0002	5587	0.25	0.00	0.0002
	Probability of gage flow >0 cfs when mod flow =0 cfs:								
					0.042				0.042
	Cumulative Probability of Intermittency:								
					0.030				0.030
ALTERNATIVES WITH ALL AWN ADDED	*Broader Flow Ranges:*								
	0	0	0.00	0.22	0	0	0.00	0.22	0
	>0-3.9	27	0.00	0.20	0.0002	5	0.00	0.20	0.00004
	4-7.9	2627	0.12	0.16	0.019	1844	0.08	0.16	0.013
	8-15.9	2527	0.12	0.10	0.011	3002	0.14	0.10	0.013
	16-24.9	6550	0.30	0.09	0.026	6344	0.29	0.09	0.025
	25-34.9	1831	0.08	0.09	0.008	2412	0.11	0.09	0.010
	35-44.9	1053	0.05	0.05	0.003	1080	0.05	0.05	0.003
	45-59.9	1700	0.08	0.03	0.002	1622	0.07	0.03	0.002
	>60	5600	0.26	0.00	0.0002	5606	0.26	0.00	0.0002
	Probability of gage flow >0 cfs when mod flow =0 cfs:								
					0.042				0.042
	Cumulative Probability of Intermittency:								
					0.027				0.025

Additionally, more than half of the time, actual gage flow will be higher than the RiverWare model predicted flow for the same time (i.e., the mean and median residual are less than 0 cfs).

The predicted probability of intermittency was examined by using an empirical model based on the raw residuals (model minus gage flow). With this model, the probabilities of intermittency (zero gage flow) within specified flow ranges for the historical (calibration) model were calculated. Empirical results were used to extrapolate conditional cumulative probability of intermittency within specific flow ranges for all of the EIS Bypass Alternatives and Alternatives with all AWN added. Overall, the cumulative probability of intermittency ranges from 0.10% to 3.6%. The probability of intermittency for the Bypass Options is generally higher than the probability of intermittency for Alternatives with all AWN added since available supply is not an issue for the latter. Results for the Bypass Alternatives indicate that the probability of intermittency is lowest for the Acme alternatives (less than 2.5%), and is highest in the case of the Pre-91 Baseline alternative (3.6%). Results for Alternatives with all AWN added indicate the probability of intermittency is lowest for the Acme alternatives (0.1 to 0.8%) and highest for the Critical Habitat alternative (2.9%).

Finally, when viewing these intermittency probabilities, it should be recognized that the empirical probability model employed conditional distributions based on the historical calibration model. In the RiverWare rules for the historical model, which are designed to reflect a decision process of the human operators, there is no accounting for a bias by the operator to avoid flow intermittencies at Acme. Therefore, it is likely that the computed intermittencies overstate what the actual expected intermittency will be, given that in the future the dam operators will include avoiding intermittency at Acme gage as one of their decision criteria.

3.0 DUNLAP GAGE

This section summarizes the findings regarding confidence intervals with respect to RiverWare model predicted flow at Dunlap gage for the historical (calibration) model. The probability of model and gage flow within specific ranges is also calculated.

This summary includes descriptions of two major tasks:

- Section 3.1 Confidence Intervals
  - Confidence interval calculations for Dunlap gage using the original model, gage, and residual data, and assuming a normal distribution.
- Section 3.2 Probability Calculations
  - Calculated probability of flow within a given range.

For the Dunlap gage, USGS daily stream flow data is available for the time period of August 20, 1993 to September 30, 2002. During this time, the lowest measured gage flow is 0.19 cfs. Modeled stream flow data for the calibrated RiverWare model is available for the time period January 1940 to December 1999. During the time of overlap analyzed (August 20, 1993 to December 1999), the model predicted river flow is not intermittent at any time, nor has the observed gage flow ever shown intermittency.

3.1 Confidence Intervals

RiverWare model predicted and USGS actual gage flow data from the Dunlap gage was used to calculate statistics and confidence intervals of model residuals. The model residual is defined as the model flow minus gage flow; a negative residual corresponds to a case where the gage flow was larger than the model flow.

Basic statistics for residuals were calculated for each of the defined model flow ranges for the Dunlap gage (for bins of 0-4, 4-8, 8-16, 16-25, 25-35, 30-40, 35-45, and 45-60 cfs). The statistics included total number of data points (N), sample mean (x), variance (σ^2), and standard deviation (σ).

Confidence intervals were calculated using the Student-t method and based on the assumption that the residuals have a normal distribution. The procedure used was adapted from Moore and McCabe (2003) and Ang and Tang (1975). For details, see Section 2.1.1. *Table 7* summarizes the statistics of each flow range and associated confidence interval that was calculated. Results of the calculated mean residual indicate that for most flow ranges (less than 60 cfs), the model flow under predicts actual gage flow; for flow greater than 60 cfs, the model tends to over predict flow.

Table 7. Summary statistics and Student-t confidence intervals of residuals calculated for modeled flow ranges at the Dunlap gage. Negative values indicate that gage flows are higher than model flows.

Flow Range (cfs)	Total number of data points, *N*	Mean Residual, *x* (cfs)	Variance, σ^2 (cfs^2)	Standard Deviation, σ (cfs)	95% Confidence Interval (+/- cfs)	99% Confidence Interval (+/- cfs)
0-4	n/d	n/d	n/d	n/d	n/d	n/d
4-8	10	-16.8	409.4	20.2	14.47	20.79
8-16	85	-21.9	6495.6	80.6	17.48	23.25
16-25	403	-32.7	14153.0	119.0	11.62	15.27
25-35	500	-16.3	1631.8	40.4	3.54	4.65
30-40	342	-20.0	2354.7	48.5	5.14	6.76
35-45	381	-21.8	2117.2	46.0	4.62	6.07
45-60	254	-22.5	1221.4	34.9	4.30	5.65
>60	692	26.3	12816.7	113.2	8.44	11.09

3.2 Probability of Flow Range

The probability of intermittency occurring is of particular interest since avoiding intermittency in parts of the Pecos River is crucial in maintaining the critical habitat for the PBNS. Crockett Draw is important in maintaining flow for the PBNS in that it is located at the end of the upper critical habitat at river mile 610.4; however, the Pecos River has no gage in this location. The Dunlap gage is located near Crockett Draw at river mile 638.9, approximately 28 miles upstream of the end of the upper critical habitat.

An additional interest is the probability of flow within a given range. Flows at the Dunlap gage tend to be higher relative to the Acme gage (Section 2.0) and historically the gage has never recorded intermittency. *Table 8* gives the empirical probabilities of gage and model flow occurrences within given ranges. Results indicate that the model generally predicts a higher probability of flow at flow ranges less than 60 cfs and under predicts the probability of flow greater than 60 cfs.

Table 8. Probability of gage and model flow within given flow ranges at the Dunlap gage.

Flow Range (cfs)	Gage flow within specified flow range (No. of occurrences)	Probability of gage flow within specified flow range	Model flow within specified flow range (No. of occurrences)	Probability of model flow within specified flow range
0	0	0	0	0
>0-3.9	0	0	0	0
4-7.9	7	0.003	10	0.004
8-15.9	159	0.07	85	0.04
16-24.9	160	0.07	403	0.17
25-34.9	225	0.10	500	0.22
35-44.9	249	0.11	381	0.16
45-59.9	420	0.18	254	0.11
>60	1105	0.48	692	0.30

Figure 4 is an exceedence curve for model and gage flow at the Dunlap gage for the entire range of observed and modeled flows. The graph illustrates that at flows less than 250 cfs, gage flow is usually higher than model flow. Between 250 and 850 cfs, trends in model and gage flow are similar. At flow ranges greater than approximately 850 cfs, the opposite occurs and model flow is generally greater than actual flow. For the case of gage flow, 58 cfs flow is exceeded 50% of the time; for the model flow, 39.94 cfs is exceeded 50% of the time. *Figure 5* is a scatterplot of gage versus model data, and confirms the pattern of model flow being generally lower than gage flow. This tendency of the model to underpredict flow has important implications when using the model to evaluate potential intermittency along the Pecos River.

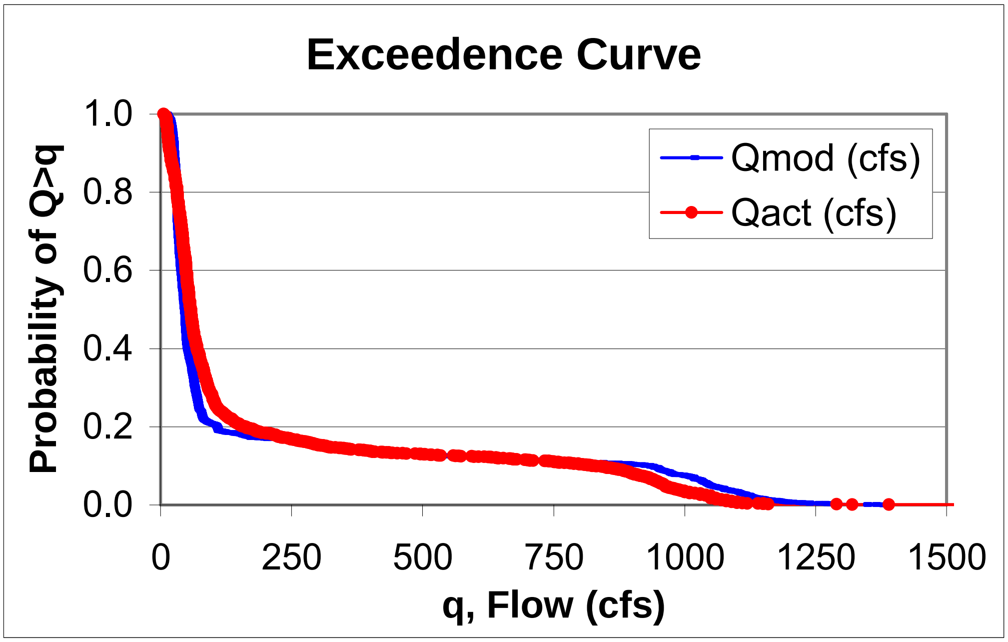


Figure 4. Probability of flow for RiverWare modeled (Qmod) and actual gage (Qact) flow at the Dunlap gage.

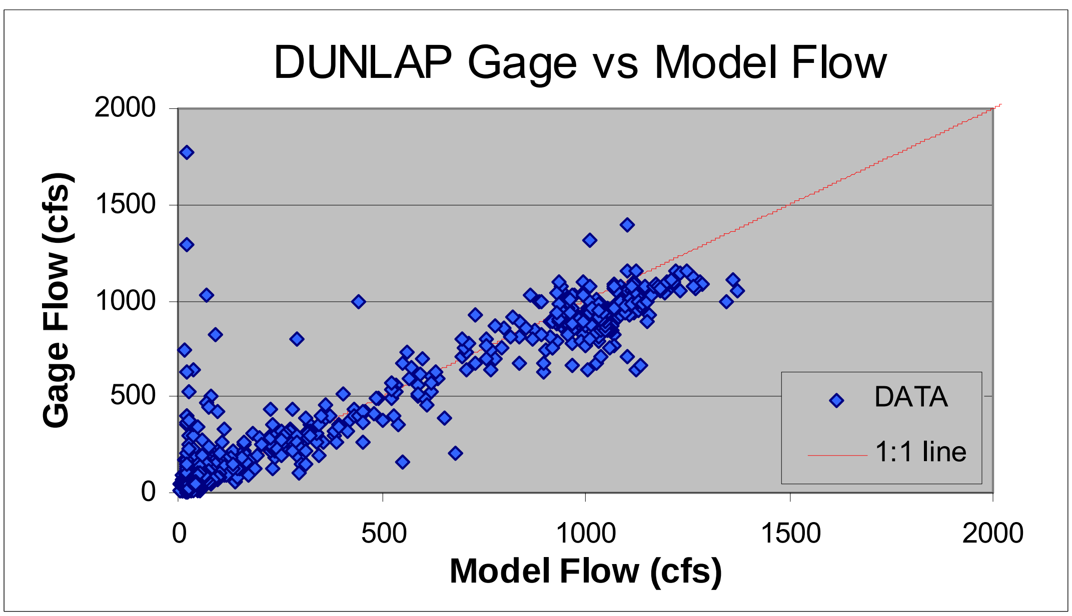


Figure 5. Scatterplot of flow for actual gage (Qact) and RiverWare modeled (Qmod) at the Dunlap gage.

3.3 Summary of Dunlap Gage Analysis

Basic statistics and Student-t confidence intervals were calculated for defined flow ranges based on a normal distribution of the historical model residual data for the Dunlap gage. More than 60% of the time, actual gage flow will be higher than RiverWare model predicted flow (residuals are less than 0 cfs). The range of 95% and 99% residual confidence intervals ranged from +/- 3.54 to 17.48 and +/- 4.65 to 23.25 cfs, respectively. The intervals are relatively large for all low flow ranges examined, and demonstrate no pattern with increasing or decreasing flow ranges.

The probability of flow within a given range indicates that gage flow at the Dunlap gage is greater than 60 cfs nearly 50% of the time, and greater than 25 cfs 85% of the time. Model flow is greater than 60 cfs 30% of the time, and greater than 25 cfs nearly 80% of the time. For most flow ranges, the RiverWare model predicted flow is lower than actual gage flow.

4.0 INTERMITTENCY TRENDS BY HYDROLOGIC SEASON

This section summarizes findings regarding length and occurrence of intermittency at Acme gage. The results of this analysis are compared by alternatives and by hydrologic season.

This summary includes descriptions of two major tasks:

- Section 4.1 Acme Intermittency
    - Calculation of the percent of the time that intermittency occurs at Acme.
    - Comparison by wet, average, or dry hydrologic season.
- Section 4.2 Length of Acme Intermittency
    - Tabulated length and count of intermittent periods.
    - Comparison by wet, average, or dry hydrologic season.

The nine alternatives considered include: No Action, Pre-91 Baseline, Acme Constant, Acme Variable, Critical Habitat, Taiban Constant, Taiban Variable HRS, Taiban Variable LRS, and Taiban Variable MRS. The determination of dry, average, and wet years (or hydrologic season) is based on effective Brantley storage along with the Palmer Drought Severity Index, as described in the 2003-2006 Fish and Wildlife Service biological opinion. An annual assessment is usually made with the possibility of adjustment throughout the irrigation season (Chapter 2 of EIS, June 2006).

4.1 Acme Intermittency

RiverWare output is daily for the time period from January 1940 to December 1999, for a total of 21,915 data points. The data used for analysis contains RiverWare model predicted flow data for all alternatives for days when Acme was intermittent, by hydrologic season. All days with intermittency were during summer months except for the Pre-91 Baseline.

Probability of intermittency, or zero flow, was calculated at Acme gage for each of the nine alternatives by hydrologic season (dry, average, or wet). *Table 9* shows the results numerically, and *Figure 6* provides a graphical illustration. During wet years, there is no occurrence of intermittency at Acme. The percent of intermittency for average years ranges from 0.10 to 0.21 % for all alternatives. As expected, the percent of intermittency during dry years is higher than wet or average, and ranges from 0.5 to 1.0 %.

Table 9: Percent intermittency for flow at Acme for each of the nine alternatives based on 21,915 total data points for the 60-year RiverWare model period.

	% Intermittency		
	DRY	**AVERAGE**	**WET**
No Action	0.77%	0.16%	0.00%
Pre-91 Baseline	1.00%	0.20%	0.00%
Acme Constant	0.50%	0.17%	0.00%
Acme Variable	0.52%	0.17%	0.00%
Critical Habitat	0.86%	0.21%	0.00%
Taiban Constant	0.69%	0.20%	0.00%
Taiban Var HRS	0.52%	0.10%	0.00%
Taiban Var LRS	0.65%	0.20%	0.00%
Taiban Var MRS	0.62%	0.18%	0.00%

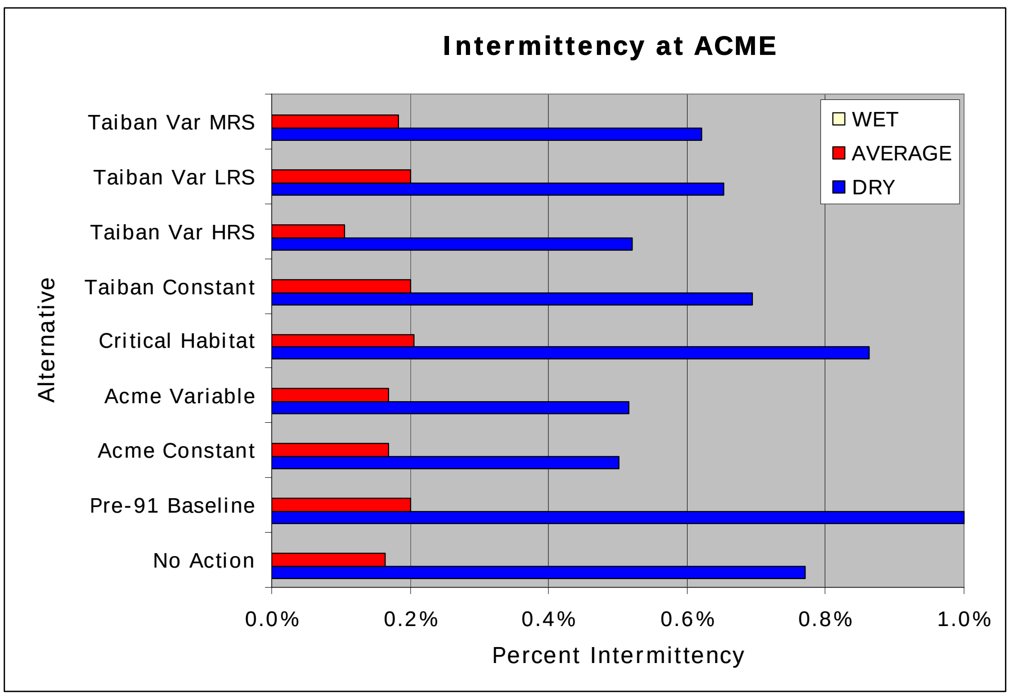


Figure 6: Bar graph showing the percent of the time that flow at Acme gage is intermittent (x-axis). Results are presented in terms of nine alternatives, located along the y-axis, and by hydrologic season (average or dry; there are no occurrences of intermittency at Acme during a wet hydrologic season). Data used to construct this figure is shown in *Table 9*.

4.2 Length of Acme Intermittency

Length of intermittency at Acme was determined for each of the nine alternatives by hydrologic season (dry, average, or wet). Length of intermittency was separated into 3 lengths: 1 to 5 days, 6 to 10 days, or more than 10 days. The results from this analysis are presented in *Table 10* and *Figure 7*. During average years, intermittent periods lasting 1 to 5 days and 6 to 10 days occur a maximum of one time throughout the period modeled for all alternatives; intermittent periods lasting more than 10 days occur one to two times for all alternatives. Dry years show a trend of longer periods of intermittency which also occur more often. Periods of intermittency lasting 1 to 5 days occur a minimum of 3 times for the Acme Constant alternative and a maximum of 12 times for the Critical Habitat alternative; periods lasting 6 to 10 days occur a minimum of 5 times (Taiban Variable LRS alternative) and a maximum of 8 times (Pre-91 Baseline); periods lasting more than 10 days occur a minimum of 3 times (Taiban Variable MRS and Taiban Variable HRS alternatives) and a maximum of 7 times (Pre-91 Baseline).

Table 10: Number of intermittent periods at Acme for each of the nine alternatives and length of intermittency, based on 21,915 total data points for the 60-year RiverWare model period.

	Number of Intermittent Periods	Length of Intermittency		
		1-5 days	6-10 days	>10 days
DRY	20	10	5	5
AVG	3	1	1	1
WET	0	0	0	0
DRY	26	11	8	7
AVG	4	1	1	2
WET	0	0	0	0
DRY	12	3	5	4
AVG	3	1	0	2
WET	0	0	0	0
DRY	14	5	5	4
AVG	3	1	0	2
WET	0	0	0	0
DRY	24	12	7	5
AVG	4	1	1	2
WET	0	0	0	0
DRY	19	10	5	4
AVG	4	1	1	2
WET	0	0	0	0
DRY	12	4	5	3
AVG	3	1	1	1
WET	0	0	0	0
DRY	15	7	4	4
AVG	4	1	1	2
WET	0	0	0	0
DRY	15	5	7	3
AVG	3	0	1	2
WET	0	0	0	0

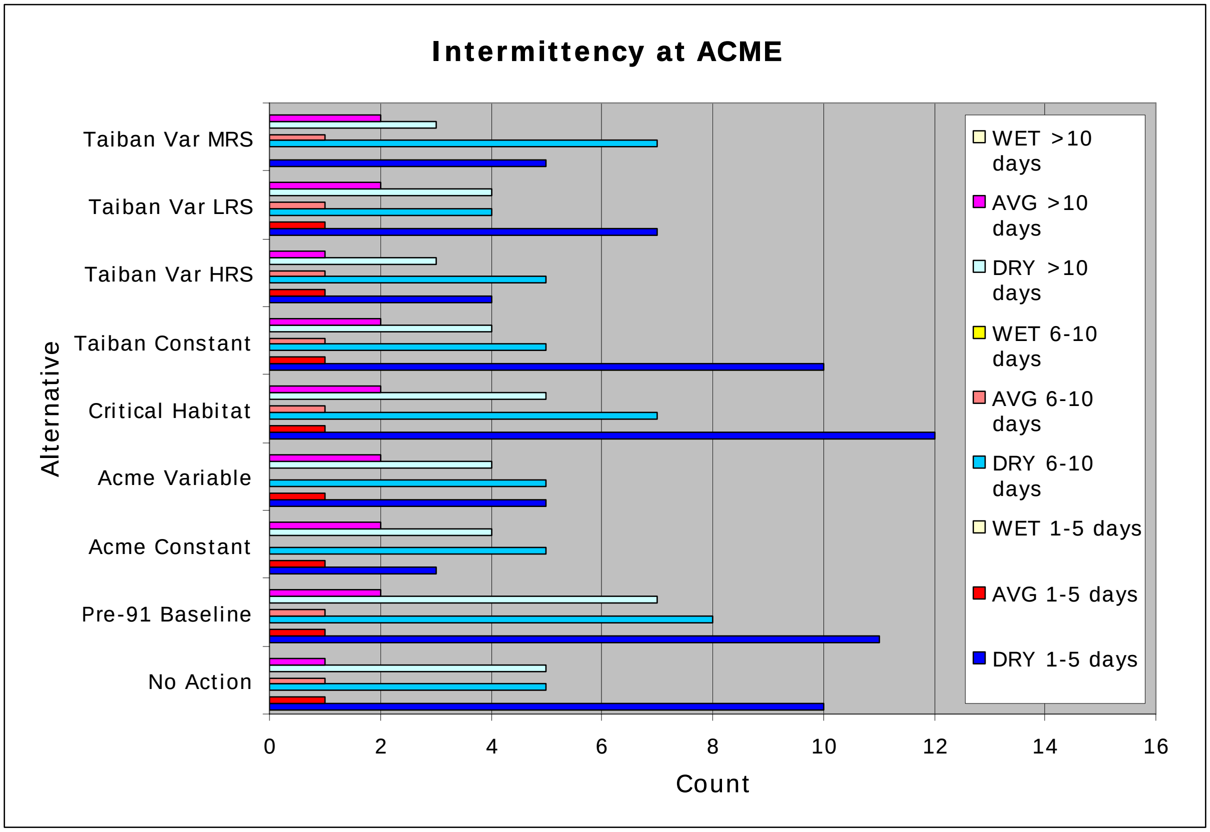


Figure 7: Bar graph showing the number of times that flow at Acme gage is intermittent (x-axis) and the length of intermittency. Results are presented in terms of nine alternatives, located along the y-axis, and by hydrologic season (average or dry; there are no occurrences of intermittency at Acme during a wet hydrologic season). Data used to construct this figure is shown in *Table 10*.

4.3 Summary of Intermittency Trends by Hydrologic Season

Intermittency at Acme gage is not common, and it occurs less than 1 % of the time when considering all alternatives for the RiverWare model predicted flows from January 1940 to December 1999. There are no occurrences of intermittency during wet years. Intermittency is more common during dry than during average years. Generally speaking, intermittency occurs nearly three times as often during dry years.

During average years, periods of intermittency at Acme gage are infrequent. During dry years, periods of intermittency occur more often and it is more likely that they will last for a longer period of time.

When analyzing intermittency along the Pecos River for the PBNS, it is important to look not only at the total percent of intermittency, but also at the length of these intermitteny periods.

Comparing intermittency by season helps us to better understand the trends. It will also enable better planning for management of the Pecos River to avoid such intermittency.

5.0 REFERENCES

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Geomorphology Memorandum

For the Pecos River Carlsbad Project
Water Supply and Conservation EIS

Written by: Alaina Briggs, P.E.

January 2006

TETRA TECH, INC.

1.0 INTRODUCTION

This memorandum is intended to supplement the information being presented in the Carlsbad Project Water Operations and Water Supply Conservation Supply EIS.

An overview of the geomorphology of the river, with particular attention to the section from Sumner Reservoir to Brantley Reservoir is summarized in this memo. In addition, this memo provides detailed descriptions of ten locations where observations were made and cross section surveys were conducted during a field visit in February of 2005. A discussion on the prediction of channel geometry for the different alternatives described in the EIS is also included.

As part of this effort, documents regarding the Pecos River geomorphology were reviewed, a field visit was conducted to observe current conditions, and previously established cross sections were surveyed and photographed. The cross section surveys and photographs help to compare changes that have occurred at specific locations within the system and lend to conclusions regarding trends of the overall reaches. In addition, calculations were made to estimate the approximate channel geometry (width and depth) that may result from the different Sumner Dam reoperation alternatives.

2.0 OVERVIEW

The geomorphology of the Pecos River system is different today than it was at the turn of the last century. Changes to the hydrology, including the construction of reservoirs, regulation of flows, changes to sediment transport mechanisms and changes to the ground water systems, have all affected the river system. Additional anthropogenic influences such as channelization and straightening of the river have also had a large impact on the geomorphology.

Today, two sections of the river between Sumner and Brantley Reservoirs have been designated Critical Habitat for the Pecos bluntnose shiner (PBNS), *Notropis simus pecosensis*. The upper critical habitat stretches approximately 58 river miles from upstream of the Taiban Creek-Pecos River confluence to immediately downstream of the Crockett Draw-Pecos River confluence. The lower critical habitat extends approximately 35 miles from just upstream of the New Mexico Highway 31 Bridge to downstream of the USGS Near Artesia gaging station. (U.S. Fish and Wildlife Service, 2002).

The Pecos River in the area of the upper critical habitat is in significantly better geomorphic condition for PBNS conservation than the lower critical habitat. From Sumner Reservoir to approximately the USGS Acme gaging station, the channel exhibits relatively good floodplain connectivity, meanders within the floodplain, and has riffle / pool sequences with point bars and macroforms, all factors that lend to diverse aquatic habitat. The much of the vegetation in the upper reaches consists of willows, sedges, grasses, and occasional tamarisks. Photo #1 is an aerial photo in the vicinity of the USGS Acme gaging station.

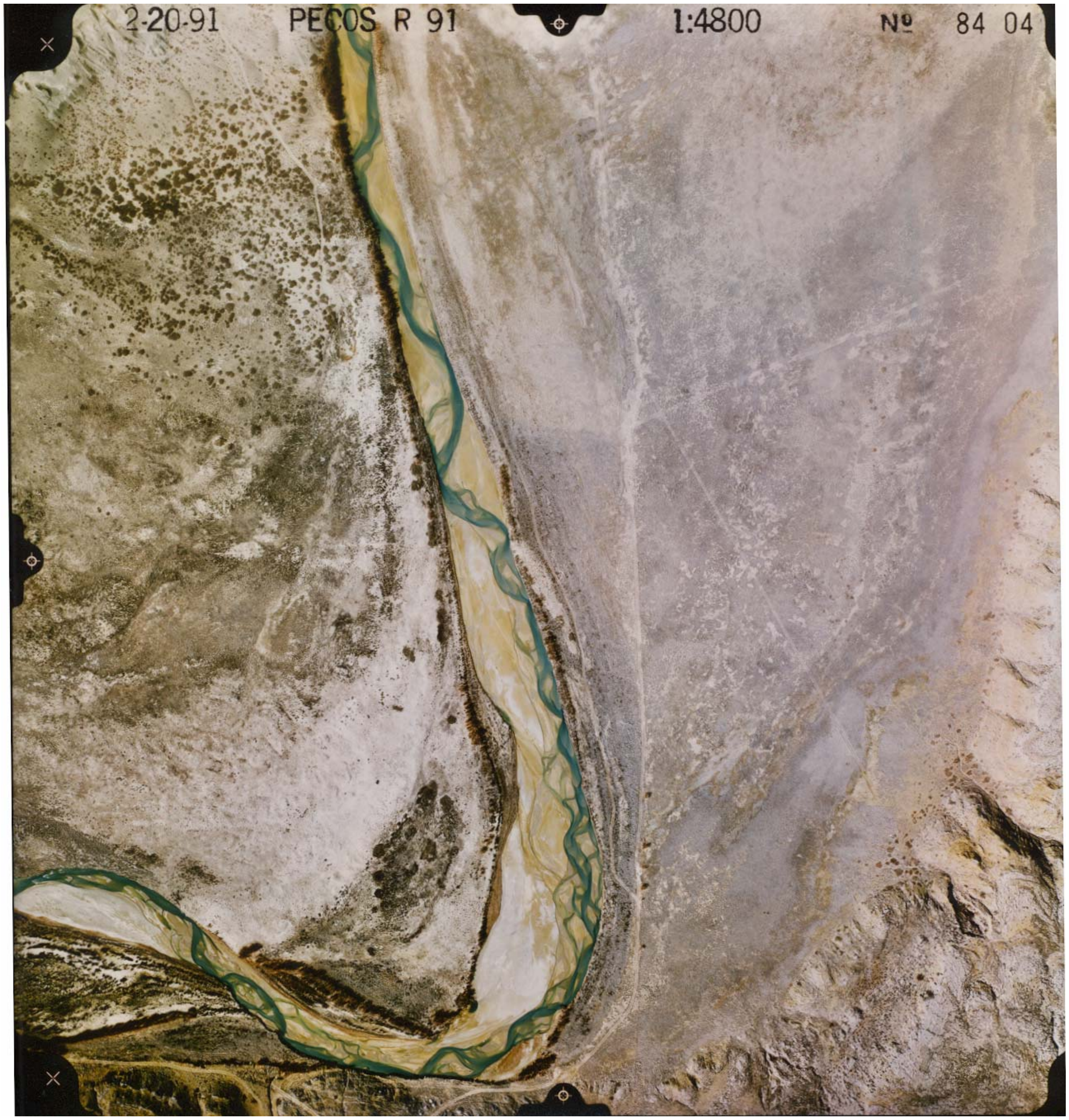

Photo #1. Aerial view of the Pecos River in the area of the USGS Acme gaging station (Photo taken February 20, 1991).

In contrast to the favorable geomorphic conditions in the upper critical habitat, the river in the lower critical habitat has been channelized in many locations. The channel in some sections, such as near the USGS Artesia gaging station and all through the Kaiser reach, was channelized for better conveyance. This channelization was subsequently fortified by the non-native invasive tamarisks trees that densely vegetate the banks, providing erosion resistance and ensuring no or limited channel migration. These areas have virtually no sinuosity, are lined with dense mature tamarisks, and have low width to depth ratios. Photo #2 shows an aerial view of the Pecos River in the area near the USGS Artesia gaging station.

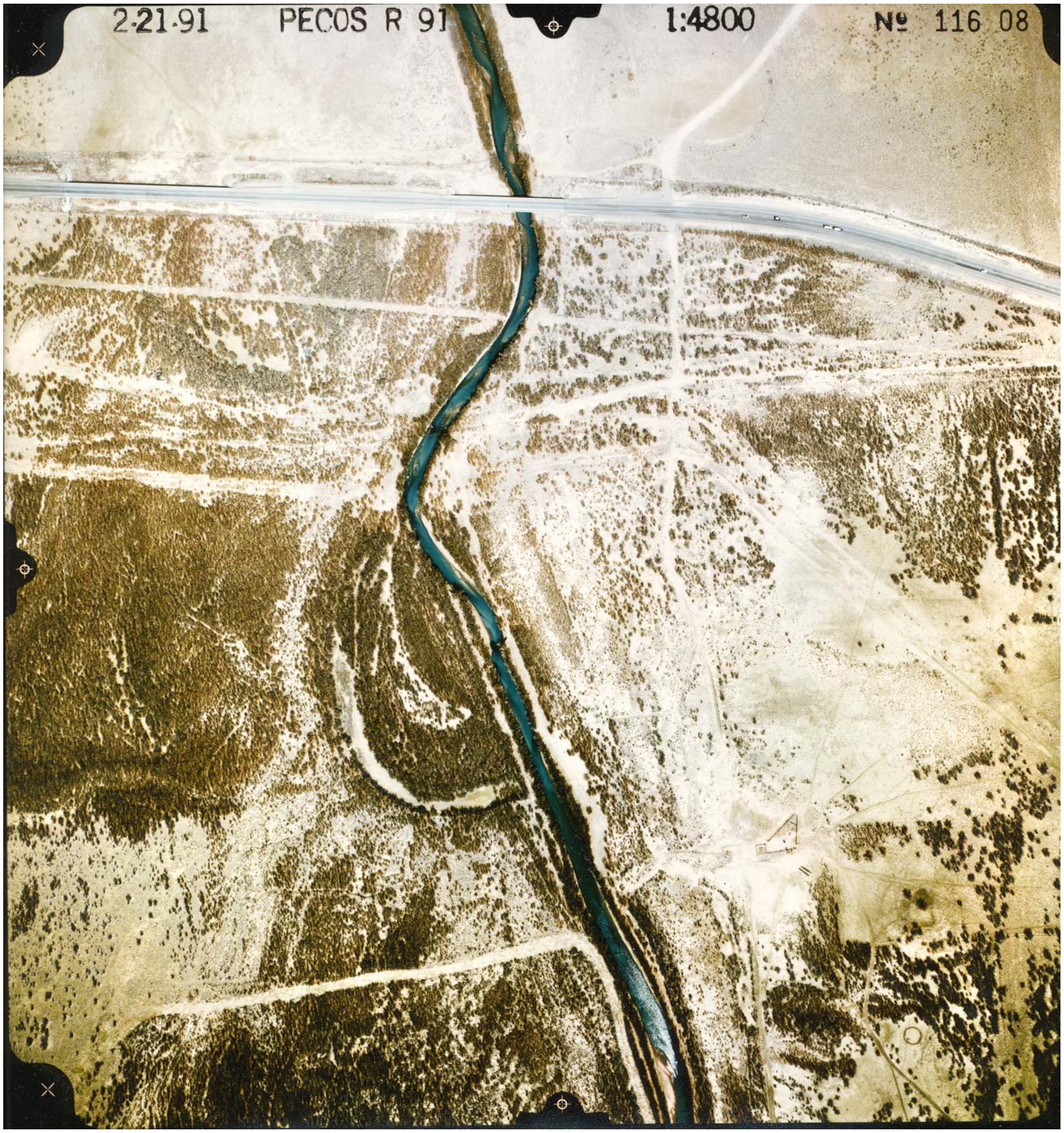

Photo #2. Aerial photograph of the Pecos River in the area near the USGS Artesia gaging station (Photo taken February 21, 1991).

Table 1 contains a summary of geomorphic parameter results taken from the Tetra Tech 2001 report. In the table, sinuosity is a measure of the relative amount of the curvature in the river system compared to the valley length, or river reach length divided by valley length. Also shown in the table is entrenchment ratio, which is the width of the current floodplain, divided by the bankfull width of the channel. In addition, the width to depth ratio (bankfull width divided by maximum depth in the thalweg at bankfull discharge) is shown along with measured channel slopes and water surface slopes.

Table 1. Geomorphic Parameters

Location	Sinuosity	Entrenchment Ratio	Width / Depth Ratio	Channel Slope (ft/ft)	Water Surface Slope (ft/ft)
Taiban	1.6	4.1	44	0.0007	0.0010
Dunlap	1.1	3.5	85	0.0020	0.0008
Above Acme	1.1	3.8	106	0.0007	0.0007
Acme	1.5	3.0	69	0.0008	0.0006
Dexter	1.0	2.2	17	0.0003	0.0004
Lake Arthur	2.3	1.3	21	0.0005	0.0005
Artesia	1.2	1.6	15	0.0012	0.0005

While performing the cross section surveys, it was observed that in the lower reaches (downstream of the Highway 380 bridge), channelized cross section fines and sands had accumulated in the overbank areas close to the channel in the tamarisk stands. This indicates that when flows do overtop the channel, the water is immediately slowed due to the dense vegetation and the sediment falls out of suspension and deposits along the banks. This process increases the height of the bank, further entrenching the channel.

During the February 2005 field trip, it was also observed that non-native vegetation eradication efforts have taken place on most public lands between Sumner and Brantley Reservoirs. Most tamarisks appeared to have been chemically treated and some had been cut. The impact on the channel will depend on the success of the eradication efforts. It is possible that with the removal of the tamarisks, the banks will lose some of the stability provided by the dense root systems and begin to erode naturally. If successful, eventually the channel may begin to meander in the historic floodplain and regain more natural sinuosity and channel geometry.

3.0 FIELD RECONNAISSANCE

A field reconnaissance and survey was conducted by Alaina Briggs, Tomas Stockton and Craig Boroughs from February 7 through 10, 2005. The purpose of the trip was two-fold: to make geomorphic observations and to perform tag line and level surveys at previously established cross sections.

A total of ten cross sections were surveyed during the field visit. The cross sections surveyed include: ST-2 Railroad Bridge, ST-3 Fort Sumner Park, ST-4 Taiban, TA-0.5 Dunlap, TA-2 Above Acme, TA-4 Near Acme, AA-1 Highway 380 Bridge, AA-1.5 Dexter Bridge, AA-3 Lake Arthur, and AA-4 Artesia. The cross sections are plotted along with previous surveys and are shown in Section 7 following the reference section at the end of the document.

Pictures were taken during the field trip and are used in this study for comparison with photographs taken as part of previous data collection efforts (September 1995 and April and May of 2000). Many of the photographs taken on the field trip are shown in the discussions below; additional pictures were included in an appendix in the original version of this document, but were removed from this version. The following sections detail the observations and survey results at the individual locations.

3.1 Pecos River below Sumner Reservoir

Photo #3 shows the Sumner Dam and outlet works. The picture was taken from the left bank looking upstream. (Left and right sides of the river are defined when looking downstream.) In this area, the channel is confined to a narrow floodplain within steep canyon walls as observed on the right side of the channel in this photo.

Photo #3. Sumner Dam and Outlet works

Photo #4 was taken from the same location as #3, viewing the river downstream of Sumner Dam. The USGS Fort Sumner gaging station and weir can be seen as well as the floodplain with willows along the banks and brush and cottonwood trees further upland.

Photo #4. Looking downstream at the USGS Fort Sumner gaging station.

Photo #5 was taken from the top of the right bank looking downstream and across the floodplain. This area is approximately 2,500 feet downstream of the Fort Sumner Diversion structure, half way between the diversion structure and the railroad bridge near Fort Sumner. The channel may have been straightened in this area, however, point bars and eroding banks indicate normal active geomorphic processes are occurring and the channel may eventually regain more sinuosity. A remnant bank can be seen in the left overbank. There are some tamarisks in this stretch of the river, especially along the left bank. However, eradication efforts were observed all along the river from Sumner to Brantley on public lands. The tamarisks appeared to have been sprayed, and some cut. Most appeared dead or dying (as evident from the brittle branches) although it was somewhat difficult to determine the extent as observations were made during the dormant season.

Photo #5. Taken 2500 feet downstream of the Fort Sumner Diversion Structure looking downstream.

3.2 ST-2 Railroad Bridge

The river in this area appears to be relatively stable with little to no changes observed in the cross section geometry when comparing the current survey with the one conducted in 1995. (See Section 7). The banks are low, indicating good geomorphic connectivity with the floodplain and the vegetation is primarily willows and sedges with some scattered mature cottonwoods in the floodplain. Photo #6 was taken at cross section ST-2 Railroad Bridge, from the right bank looking downstream at the channel, bridge, and right bridge abutment.

Photo #6. Looking downstream from the right bank at the ST-2 Railroad Bridge cross section.

3.3 ST-3 Fort Sumner Park

The river in the area of this cross section has been recently altered by heavy machinery. In looking at the cross section plot comparing 1995 to 2005 surveys, the left channel has filled slightly and the right channel has degraded. However, it is difficult to determine what extent was caused naturally and what was caused by machinery. The channel appears to have been reworked to facilitate vehicle crossings during low flow. Additionally it appears that some of the bars have been reworked and leveled out as well. Photo #7 was taken from the left end point looking towards the right end point (the right end point was missing), note the large tire tracks.


Photo #7. At cross section ST-3 Fort Sumner Park, from the left end point looking towards the right end point.

3.4 ST-4 Taiban Gage

The Pecos River near the Taiban gage is in a natural, relatively undisturbed state. The floodplain in this area is very wide and the channel exhibits natural meandering and sinuosity. The vegetation is primarily willows and grasses with some tamarisks. The cross section has experienced relatively little change since 1995 with the exception of some bank erosion along the right bank.

Photos 8 and 9 both show the Taiban gage. Photo 8 was taken in 2000 when most of the flow was along the left bank. During these periods, the gage can be assumed to be effective in determining discharge. The opposite is true in Photo 9 where the flow is more on the right side of the channel and the area around the gage is dry. This likely interferes with the accuracy of the gage under low flow conditions.

Photo #8. USGS Taiban gage photographed in 2000.

Photo #9. USGS Taiban gage photographed in 2005.

3.5 TA-0.5 Dunlap Site

Comparing the February 2005 survey with previous surveys, the cross section at TA-0.5 Dunlap has experienced relatively little change since the 1995 survey. A thalweg on the right side of the channel has filled slightly and a center bar has degraded slightly, both indications of natural channel migration. The banks have remained stable, especially on the left where the bank is a steep cliff due to a local fault.

Photo #10. Near cross section TA-0.5 looking upstream, taken in 2000.

Photo #11. Photo from the left bank at TA-0.5 Dunlap looking upstream; picture taken in 2005.

3.6 TA-2 Above Acme

The river at TA-2 Above Acme is in good geomorphic shape. Some shifting of the bed is observed from the cross section plot as is natural, especially in alluvial channels such as the Pecos River. Photo #12 shows the channel in 2000, with bars and macroforms observed in the main channel. Photo #13 was taken in a similar location. The bed of the channel is similar and some scattered tamarisks can be seen on the banks.

Photo #12. Above Acme USGS gage site looking upstream at active outer bank erosion, taken in 2000.

Photo #13. Photo taken at the Above Acme site, left bank looking upstream, taken in February 2005.

3.7 TA-4 Acme Gage

The river in the area of the Acme gage is located against a bluff on the right side of the floodplain. This portion of the river has some tamarisks along the banks with primarily wide open floodplain as can be observed in photos 14 and 15. Meandering occurs naturally here, the river in this reach has not been channelized or armored.

The cross section plot (Shown on page H-34) for TA-4 shows that there has been little change to the cross section since 1995 with the exception of some normal shifting of the thalweg from the right to the left side of the channel.

Photo #14. Looking at the Acme gage crossing and the left floodplain, taken in 2000.

Photo #15. Looking at the Acme gage site and the left floodplain, taken in 2005.

3.8 AA-1 Highway 380 Bridge

The river in the vicinity of the Highway 380 bridge is very uniform and appears to have been channelized. As can be seen in Photo #16, the channel banks are lined with dense tamarisks further ensconcing the channel in place. Deposition has occurred at this cross section since the 1995 survey. An average of 2 feet of deposition in the main channel and 1 foot in the overbanks is seen on the cross section plot. This section was not surveyed in 2000, and therefore there are no photographs to use for comparison.

Photo #16. Looking upstream from the center of the channel at AA-1 Highway 380 cross section.

3.9 AA-1.5 Dexter Gage

The cross section at the USGS Dexter gaging station is very similar to the Highway 380 cross section. The channel in this area is also very uniform, very straight and lined with dense tamarisks. Photos #17 and #18 show the channel looking upstream. The photos were taken at different times of the year, and show the difference of the vegetation during dormant and active seasons.

Deposition has also occurred at this cross section, with an average of 1 foot in the channel and roughly 0.5 feet in the overbanks between 1995 and 2005.

Photo #17. From the center of the channel at the Dexter gage looking upstream, taken during 2000.

Photo #18. From the center of the channel at the Dexter gage looking upstream, taken during 2005.

3.10 AA-3 Lake Arthur Gage

The cross section at the Lake Arthur gage has experienced some degradation in the past 5 years. The left side of the channel has degraded up to 2.5 feet. The channel in this reach is also very uniform with steep, stable banks and limited sinuosity. Comparing the two photos below (one taken in 2000 and the other in 2005), it is apparent that little change has occurred in the channel shape and in the vegetation on the banks.

Photo #19. Looking upstream at the USGS Lake Arthur gage, taken in 2000.

Photo #20. Looking upstream at the USGS Lake Arthur gage, taken in 2005.

3.11 AA-4 Artesia

The cross section at Artesia is relatively stable, with some deposition occurring on the right bank over the last 10 years. The channel is very uniform, with little sinuosity or diversity in aquatic habitat. Comparing the two photos below (taken 5 years apart), it is apparent that little change has occurred in the channel shape and in the vegetation on the banks.

Photo #21. Looking upstream from below the bridge near Artesia (cross section AA-4 is just upstream of the bridge), photo taken in 2000.

Photo #22. Looking downstream from the Artesia cross section (AA-4) at the bridge near Artesia, photo taken in 2005.

4.0 CHANNEL GEOMETRY PREDICTION

In 2003, Tetra Tech, Inc. performed a study for the Bureau of Reclamation on the Pecos River. The study involved determining a way to predict channel geometry based on dominant or effective discharge[15].

In the 2003 study, cross section information from an undisturbed portion of the Pecos River in the Bitter Lake National Wildlife Refuge was used to generate hydraulic information using HEC-RAS (USACE, 2002). The hydraulics were in turn used to estimate sediment transport rates for the known range of flows for the Acme gage. For each discharge rate, a corresponding sediment transport rate was estimated. The frequency of the discharge was determined by creating bins of flow and performing a histogram analysis. From the frequency, the probability of occurrence was calculated. The probability of occurrence is multiplied by the sediment transport rate for a representative discharge for each bin and divided by the size of the corresponding bin since the bins are not all of equal size. The result is referred to as the incremental sediment transport rate that has units of tons/day/cfs. The discharge that corresponds to the highest incremental sediment discharge rate is the dominant discharge. Table 2 below shows an example of the calculations.

This process was used in the 2003 study to determine the dominant discharge for the flows at Acme based on three scenarios unrelated to the current EIS alternatives. The three scenarios were selected to demonstrate the effects of vastly different operating conditions.

With the dominant discharge known, the coefficients for the channel geometry prediction equations (shown below) were determined, thus calibrating the equations for the area of the study.

Three sub-reaches were defined in the 2003 study and the equations determined for each reach are:

Reach 1:	$W = 3.98\ Q_d^{\ 0.5}$	$D = 0.138\ Q_d^{\ 0.4}$
Reach 2:	$W = 3.54\ Q_d^{\ 0.5}$	$D = 0.135\ Q_d^{\ 0.4}$
Reach 3:	$W = 4.39\ Q_d^{\ 0.5}$	$D = 0.154\ Q_d^{\ 0.4}$

[15] "The dominant or effective discharge is defined as the single discharge (resulting from a range of flows) at which the sediment transport capacity multiplied by the frequency of occurrence (incremental sediment transport rate) yields the largest portion of sediment transported by the system relative to other flows (Thorne, 1997)." Tetra Tech, 2003

Table 2. Calculation of Dominant Discharge for Acme Constant with Bypass Flows Only

Sediment Transport Rates (tons/day)				Acme Constant				
						Incremental Transport Rate (tons/day/cfs)		
				Frequency	*Probability*	*Reach 1*	*Reach 2*	*Reach 3*
Discharge (cfs)	Reach 1	Reach 2	Reach 3					
0	0	0	0	147	0.0067			
7	2	1	2	1515	0.0691	0.01	0.01	0.01
14	7	7	6	2571	0.1173	0.08	0.08	0.07
24	18	17	15	1623	0.0741	0.13	0.13	0.11
35	33	32	30	8388	0.3828	1.28	1.24	1.13
45	51	49	45	1284	0.0586	0.30	0.28	0.26
55	72	67	63	1203	0.0549	0.40	0.37	0.35
65	96	86	83	473	0.0216	0.21	0.19	0.18
75	122	108	106	300	0.0137	0.17	0.15	0.14
85	151	132	130	336	0.0153	0.23	0.20	0.20
95	181	157	156	346	0.0158	0.29	0.25	0.25
105	213	183	183	267	0.0122	0.26	0.22	0.22
115	246	212	212	206	0.0094	0.23	0.20	0.20
125	282	241	243	155	0.0071	0.20	0.17	0.17
135	314	272	275	104	0.0047	0.15	0.13	0.13
145	352	303	308	108	0.0049	0.17	0.15	0.15
155	392	336	341	88	0.0040	0.16	0.13	0.14
165	434	370	376	71	0.0032	0.14	0.12	0.12
175	476	405	413	71	0.0032	0.15	0.13	0.13
185	520	441	451	60	0.0027	0.14	0.12	0.12
195	565	478	490	50	0.0023	0.13	0.11	0.11
245	815	673	698	359	0.0164	0.13	0.11	0.11
346	1407	1153	1188	308	0.0141	0.20	0.16	0.17
447	2111	1718	1759	182	0.0083	0.18	0.14	0.15
548	2910	2358	2381	169	0.0077	0.22	0.18	0.18
648	3787	3058	3048	110	0.0050	0.19	0.15	0.15
748	4739	3815	3744	170	0.0078	0.37	0.30	0.29
849	5762	4644	4474	184	0.0084	0.48	0.39	0.38
949	6681	5539	5210	287	0.0131	0.87	0.73	0.68
1025	7965	6621	5661	346	0.0158	**2.52**	**2.09**	**1.79**
1075	8569	7147	5996	118	0.0054	0.92	0.77	0.65
1125	9172	7673	6331	42	0.0019	0.35	0.29	0.24
1175	9776	8199	6666	23	0.0010	0.21	0.17	0.14
1224	10376	8723	6999	18	0.0008	0.17	0.14	0.12
1250	10684	8991	7169	0	0.0000	0.00	0.00	0.00
1275	10985	9254	7337	17	0.0008	0.17	0.15	0.11
1325	11586	9778	7670	12	0.0005	0.13	0.11	0.08
1375	12189	10304	8005	9	0.0004	0.10	0.08	0.07
1449	13085	11085	8501	30	0.0014	0.18	0.15	0.12
1732	16760	14369	10249	54	0.0025	0.08	0.07	0.05
2236	24118	21252	13882	24	0.0011	0.05	0.05	0.03
2739	30614	29309	17528	12	0.0005	0.03	0.03	0.02
3122	36377	35996	20251	7	0.0003	0.05	0.05	0.03
3373	40147	39463	21519	6	0.0003	0.04	0.04	0.02
3742	47589	49934	31210	5	0.0002	0.02	0.02	0.01
4472	62539	75418	44512	21	0.0010	0.06	0.07	0.04
6124	103028	95210	87393	23	0.0010	0.04	0.04	0.04
8660	183270	163647	144024	4	0.0002	0.01	0.01	0.01
12247	334094	316315	298536	5	0.0002	0.02	0.01	0.01
17321	622079	565064	508048	2	0.0001	0.01	0.01	0.01
24495	1178727	1135399	1092072	2	0.0001	0.01	0.01	0.01
			MORE	0				
			TOTAL	21915	1.0000			

4.1 Bypass Flows Only

For this study, the dominant discharge, Q_d, for each of the EIS alternatives was determined and entered into these equations. The goal of this exercise was to determine if the different alternatives would result in different channel geometry in the long run.

The dominant discharge for the bypass only EIS alternatives was a fairly straight forward calculation. First, a range of discharge values that encompassed all flows for the Acme gage (values were determined from RiverWare model output) were determined. Next, the range was broken down into a series of bins. The flow record for the modeled Acme gage was then separated into bins and the frequency of each flow (the median flow value represented by the bin) was determined. The probability of occurrence was calculated based on the frequency and the total number of occurrences. The sediment transport rate for each flow value was determined as part of the 2003 study. This value was multiplied by the probability of occurrence. The largest value determined by this product represents the dominant discharge. The results of the "bypass only" flows are shown in Table 2.

The results showed little to no variation in the dominant discharge among alternatives with bypass water only, as shown in Table 4. Note that the values depicted in Table 4 are the median values of the bins used to define ranges of flows. In this case, 1,075 cfs is the median of the range from 1,050 to 1,100 cfs, likewise, 1,000 – 1,050 cfs is the range that encompasses 1,025 cfs.

In addition to the analysis of the alternatives that used bypass flows only, another set of alternatives that added all the required water to meet all the Pecos blutnose shiner's (PBNS) needs (defined as targets in the alternatives) was analyzed as well. This second set of alternatives, dubbed "with Carlsbad Project supply" represents the scenario where water would be released from Sumner Reservoir to supplement bypass flows, therefore decreasing the water available for Carlsbad Project supply.

4.2 With Carlsbad Project Supply

The determination of the dominant discharge for the "with Carlsbad Project supply" was a bit more complicated. As part of the EIS process, a "mini-model" was executed to determine the amount of water needed each year (1940 – 1999) to meet the additional water needs of the PBNS not met by the bypass flows alone. The "mini-model" spanned from Sumner to Acme, but did not extend downstream as far as Brantley Reservoir. The results therefore contain block releases from Sumner Dam as they would have occurred in the bypass only scenario. However, it is likely that some of the water released for the PBNS would reach Brantley Reservoir and decrease the need for block releases from Sumner Reservoir.

In order to alter the available information to more accurately represent the "with Carlsbad Project supply" condition, the amount of water need for the PBNS was determined for each year. This volume was then subtracted from the volume of water discharged out of Sumner Dam in block releases and the flow frequencies were recalculated. The number of days of block releases for the bypass only and for the "with Carlsbad Project supply" are shown in Table 3. As can be seen, there is not a very large difference between the two scenarios. The exception is the Acme Constant alternative which has a decrease of 270 days in block releases for the "with CID supply" scenario.

Results for the dominant discharge for the "with Carlsbad Project supply" scenario are shown in Table 4. As can be seen, the changes in the block release flow values are not large enough to make a difference in the dominant discharge.

Table 3. Number of Days of Block Releases During Period of Study (1940 – 1999)

	Acme Constant	Acme Variable	Taiban Constant	Taiban Variable 55 cfs	Taiban Variable 40 cfs	Taiban Variable 45 cfs	Critical Habitat	No Action
Bypass Only	650	660	750	725	750	740	750	750
With Carlsbad Project Supply	380	510	730	605	710	675	730	670

Table 4. Dominant Discharge (cfs)

	Alternative								
	Pre-91	Acme Constant	Acme Variable	Taiban Constant	Taiban Variable 55 cfs	Taiban Variable 40 cfs	Taiban Variable 45 cfs	Critical Habitat	No Action
Bypass Only	1,025	1,025	1,025	1,025	1,025	1,025	1,025	1,025	1,025
With Carlsbad Project Supply	1,025	1,025	1,025	1,025	1,025	1,025	1,025	1,025	1,025

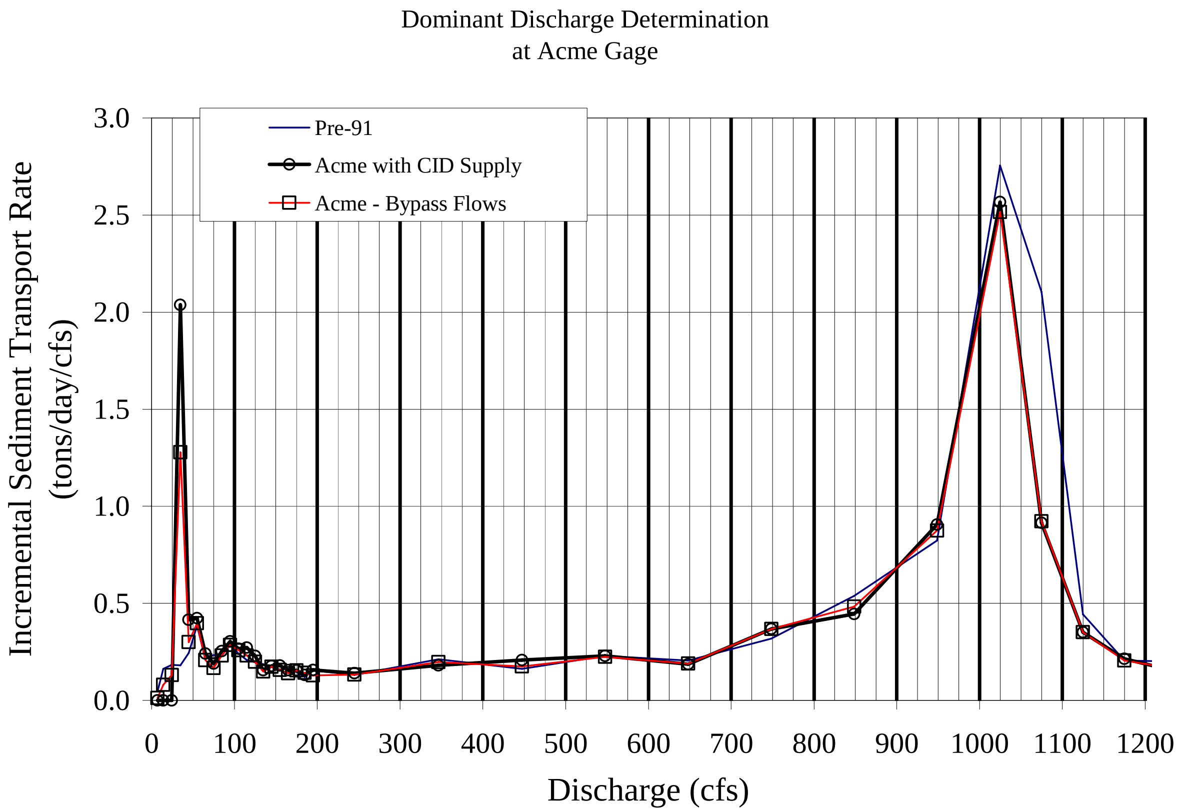

Figure 1. Graph of Dominant Discharge for Pre-91, Bypass Flows and With Carlsbad Project Supply conditions at the Acme gage for the Acme Constant Alternative.

Figure 1 shows the incremental sediment transport rate versus the discharge for bypass operations under the alternatives and the Pre-91 baseline. From this figure, it can be seen that the dominant discharge for the Pre-91 condition is 1,025 cfs. This is the value that corresponds to the highest incremental sediment transport rate, approximately 2.76 tons/day/cfs. Likewise, the dominant discharge for the Acme Constant alternative with Bypass Flows only and the Acme Constant alternative with unlimited use of Carlsbad Project Water is 1,025 cfs, corresponding to an incremental sediment transport rate of approximately 2.57 tons/day/cfs. This slightly lower incremental transport rate is essentially due to the block release constraints imposed by the alternatives.

Using the average of the three reaches and putting in a range of dominant discharge values, Figure 2 was created. This demonstrates how the channel width and depth are expected to decrease with decrease in dominant discharge.

Using the channel geometry equations and the results listed in Table 3, the channel width and depth under Pre-91 and alternative operation conditions could be expected to average 127 feet and 1.8 feet, respectively. Although the results show no change between the alternatives and the baseline, Figure 1 indicates that additional reductions in block flows (beyond Acme Constant using all of CID's supplies) and subsequent redistribution of those flows in the target ranges considered by the alternatives may cause the channel to change shape. For example, if the higher flows were reduced further and the dominant discharge dropped to 45 cfs, the channel width prediction would be 27 feet and the depth would be 0.6 feet.

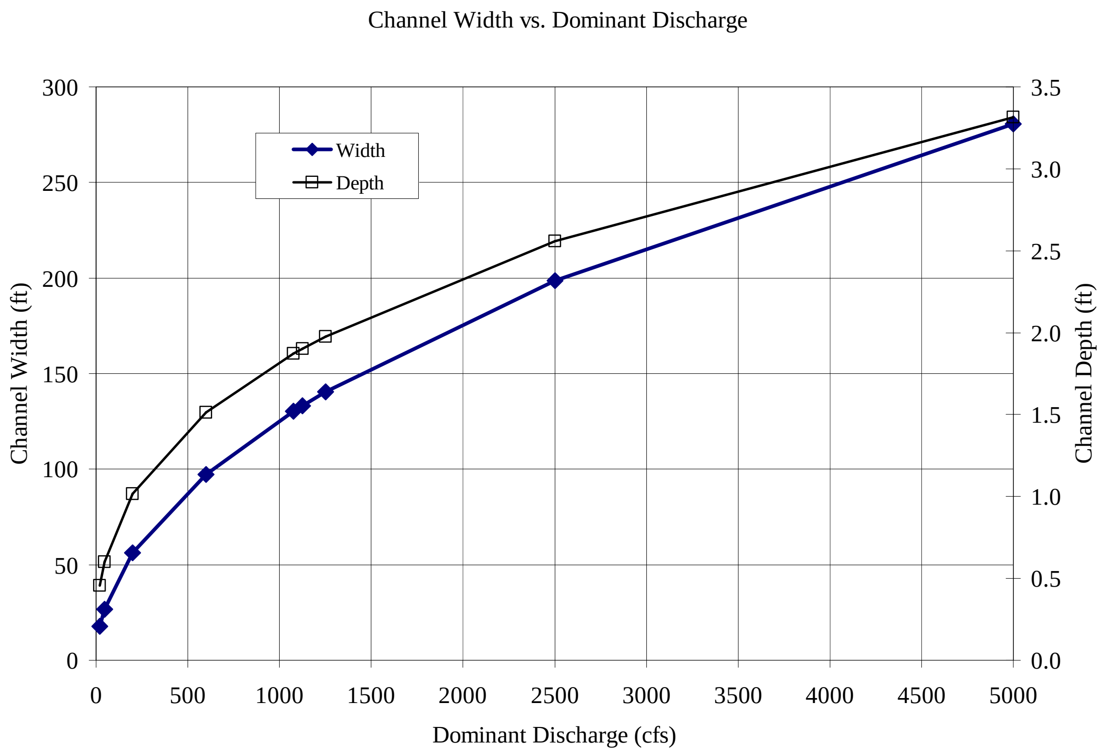

Figure 2. Predicted Channel Width and Depth versus Dominant Discharge

5.0 CONCLUSIONS

The Pecos River between Sumner and Brantley Reservoir has widely varied geomorphology and aquatic habitat conditions. The upper critical habitat is in a section of the river that has not been as dramatically altered as is the case in the lower critical habitat. The upper portions, from Sumner Reservoir to roughly the Acme gage, has been affected by the changes to hydrology, diversion structures, return flows, etc.; however, some natural characteristics such as good floodplain connectivity and channel shape still exist.   In the lower portions of the river, previous channelization efforts have caused the channel to become very canal like, held in place with dense, mature tamarisks.

The channel geometry prediction equations show that with lower dominant discharges, a decrease in channel width and depth can be expected. Based on the results of the modeling efforts for the different alternatives and scenarios, a large change would not be expected in the channel geometry. However, should the block releases be lowered or eliminated altogether, a bigger impact on the channel is to be expected as demonstrated in Figure 2.

6.0 REFERENCES

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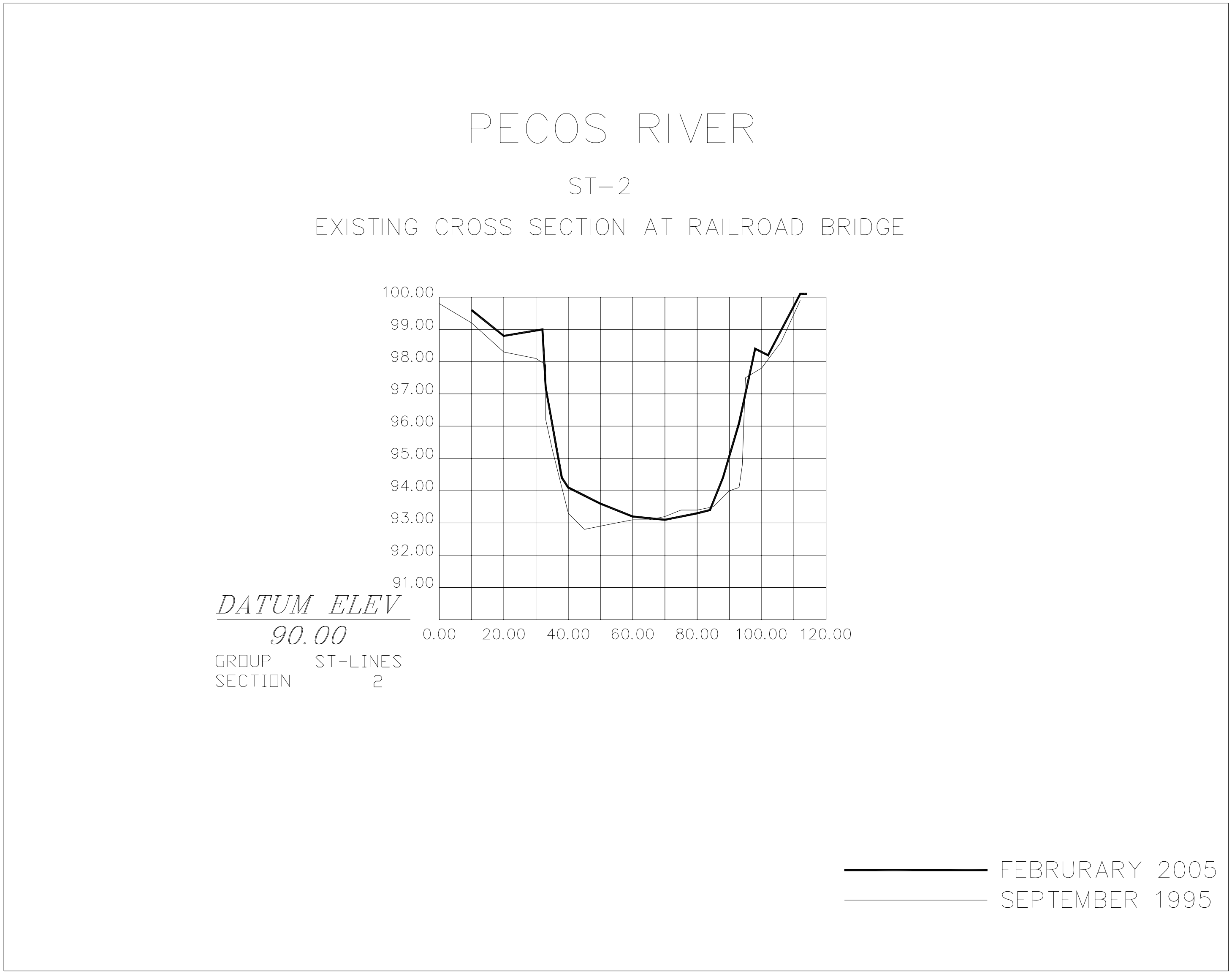
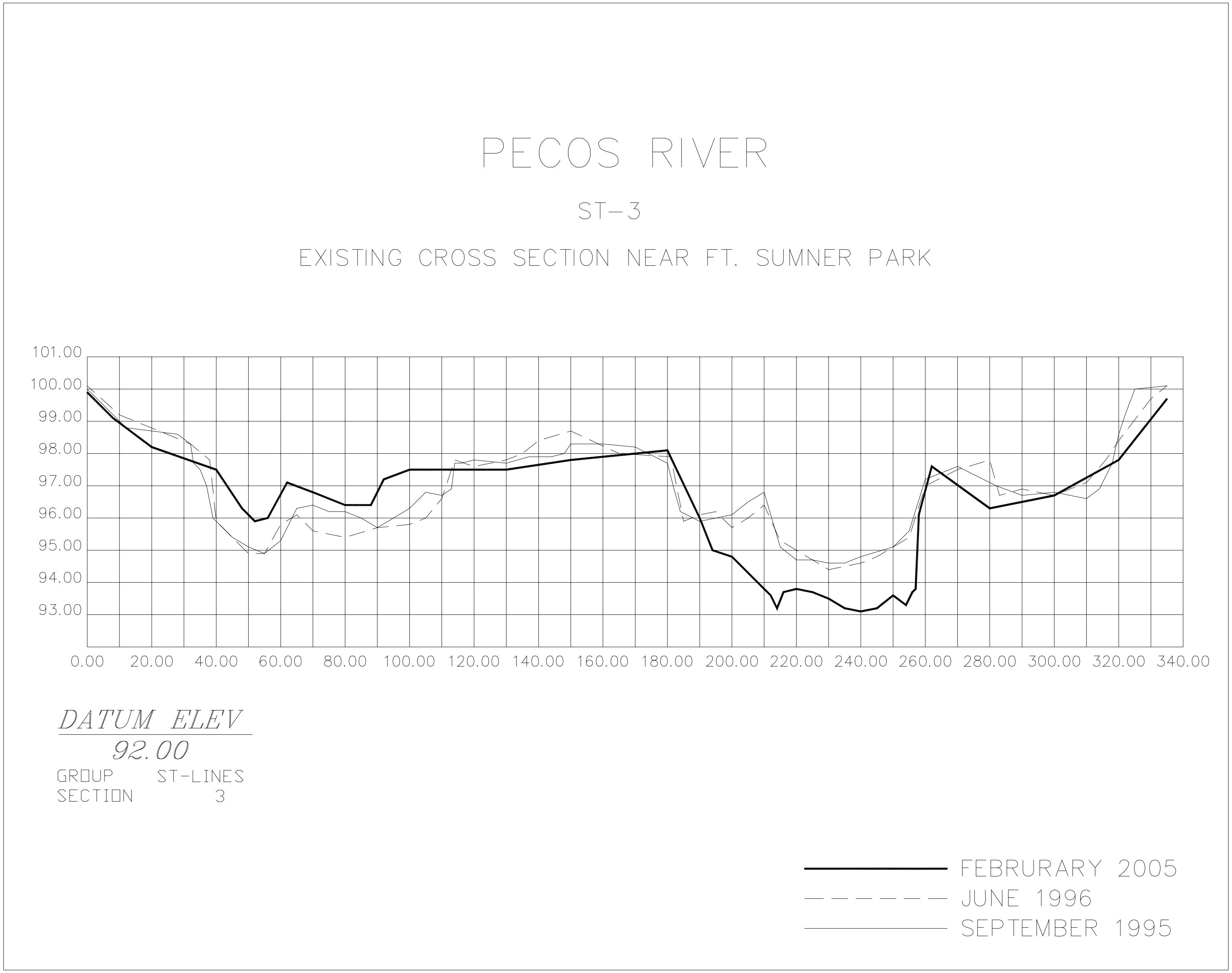
7.0 CROSS SECTION PLOTS 2005 DATA COLLECTION

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60.00
80.00
100.00
120.00
140.00
160.00
180.00
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240.00
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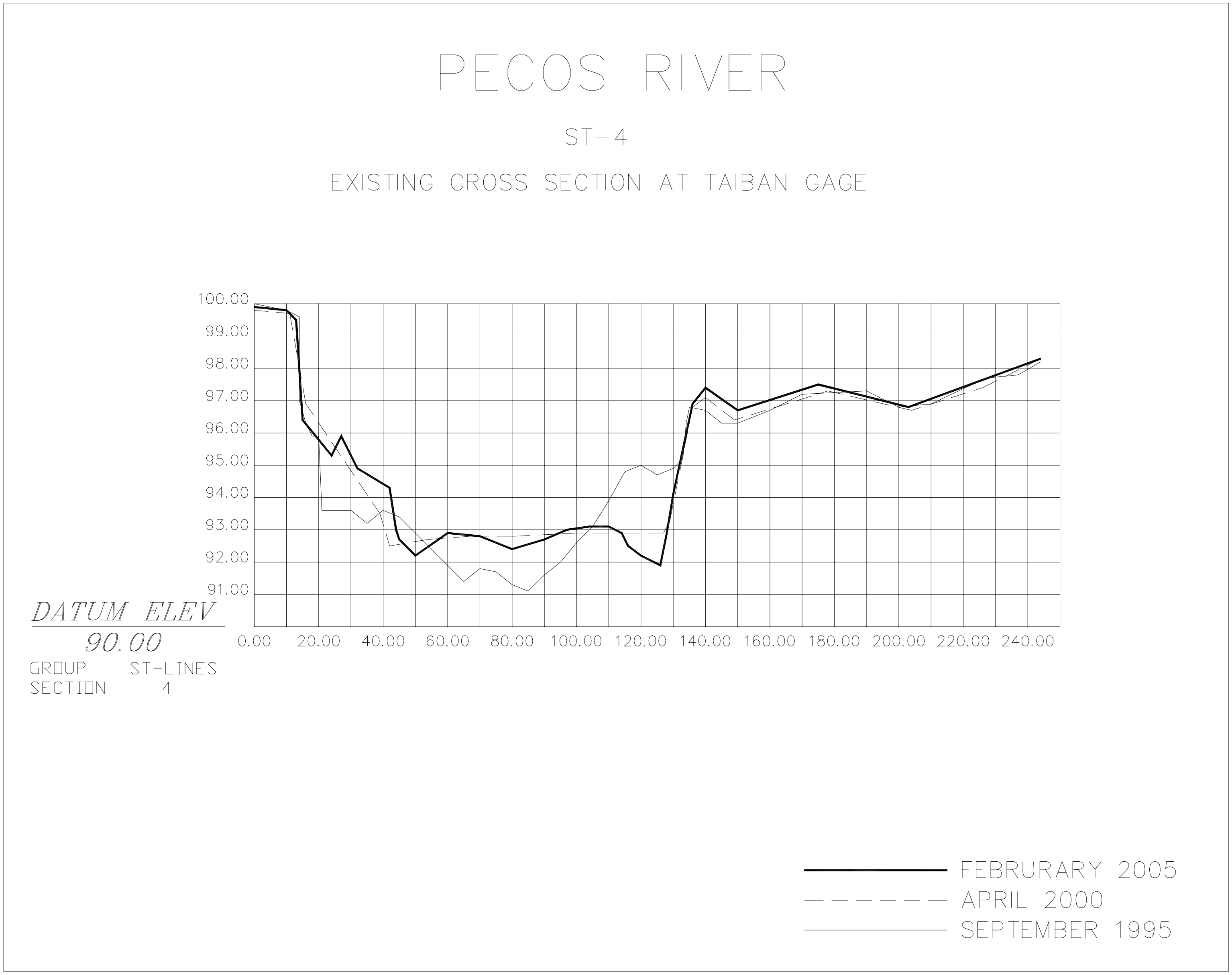
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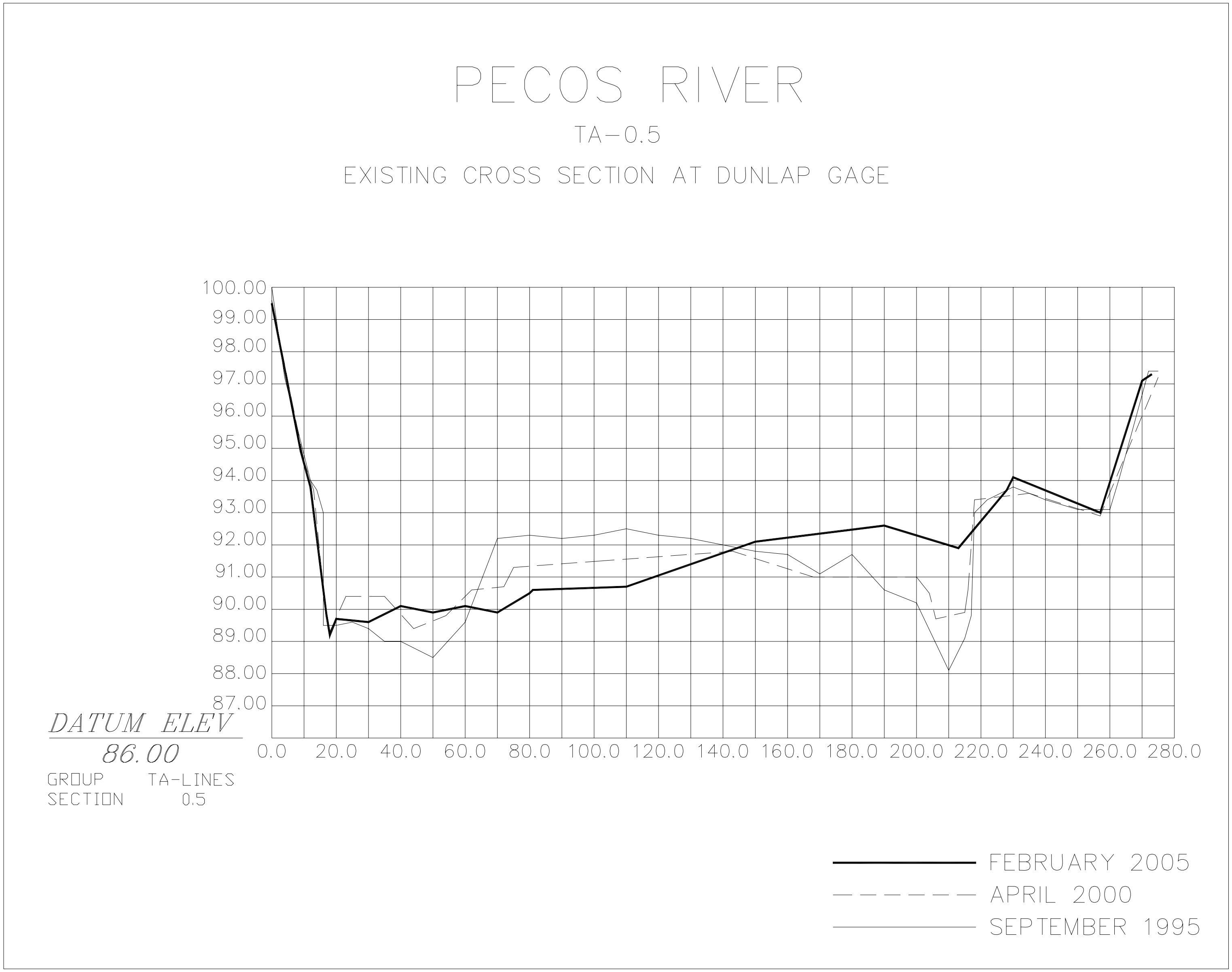
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88.00
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DATUM ELEV
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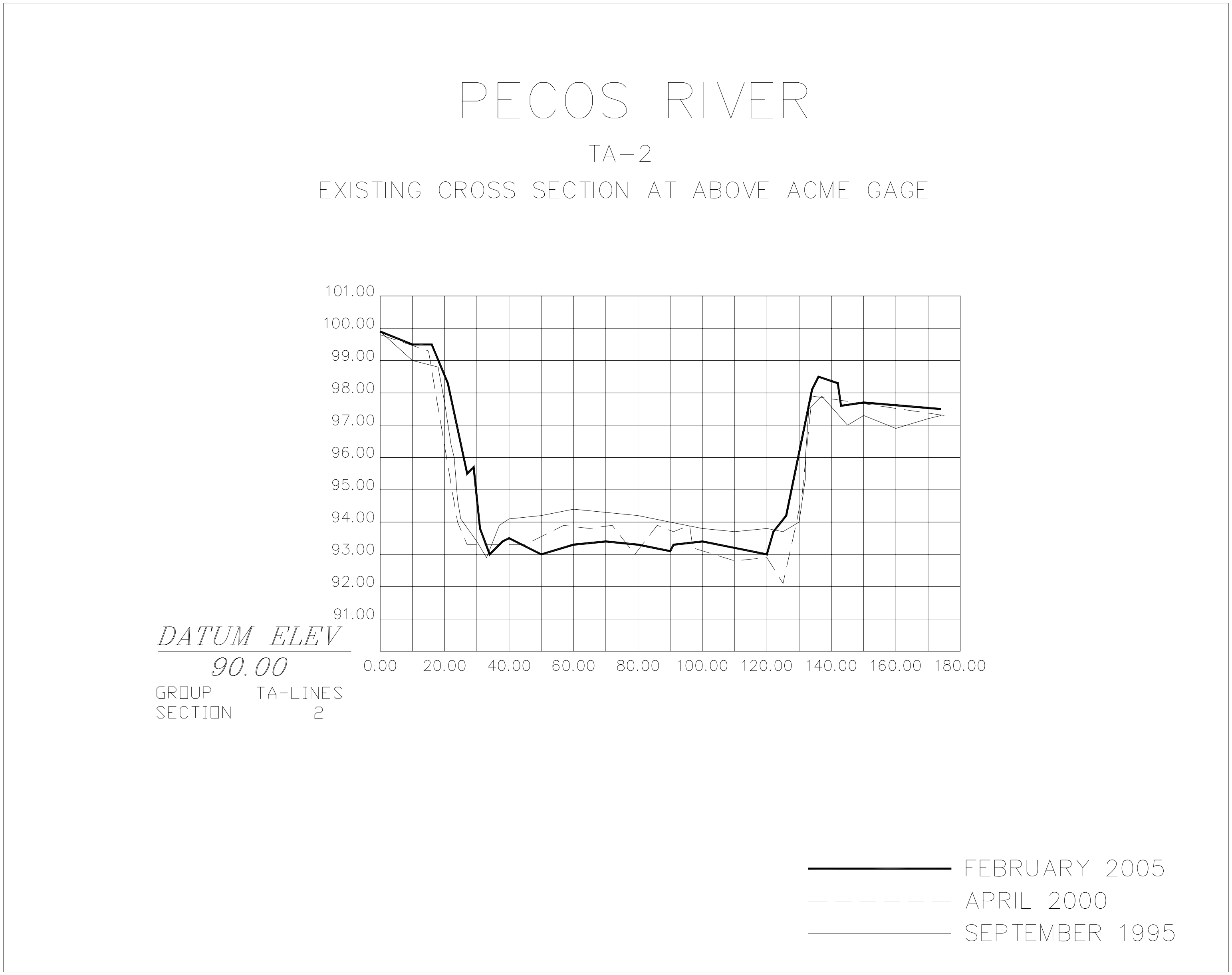
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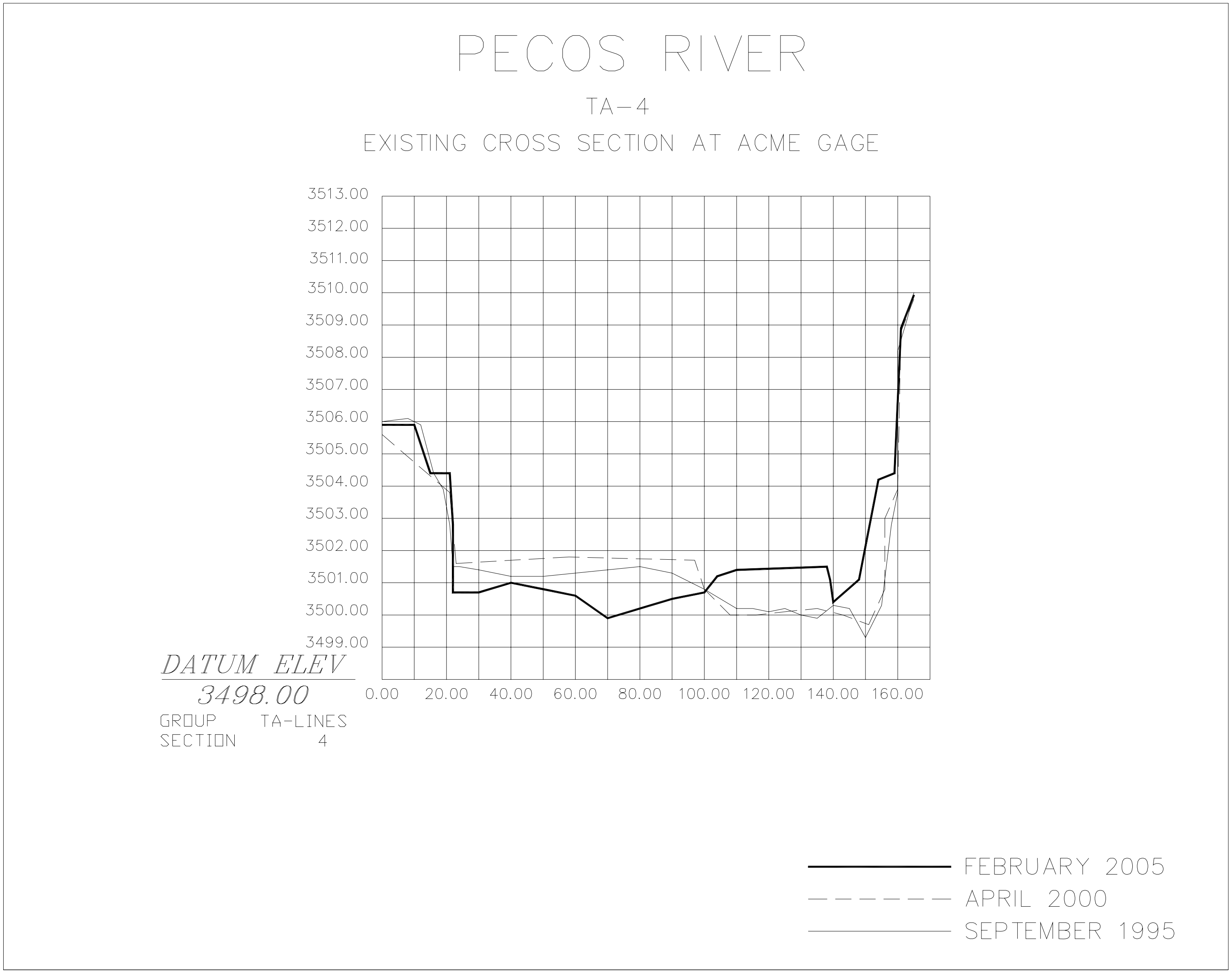
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PECOS RIVER

AA-1

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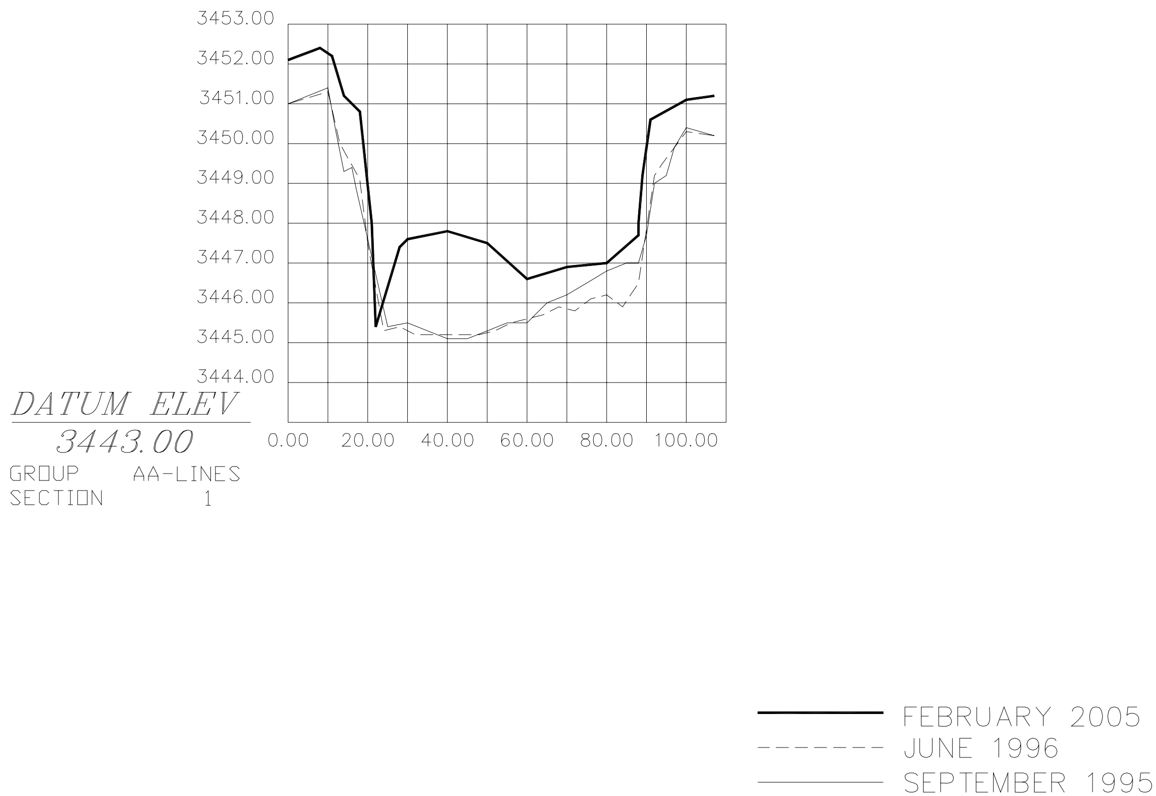

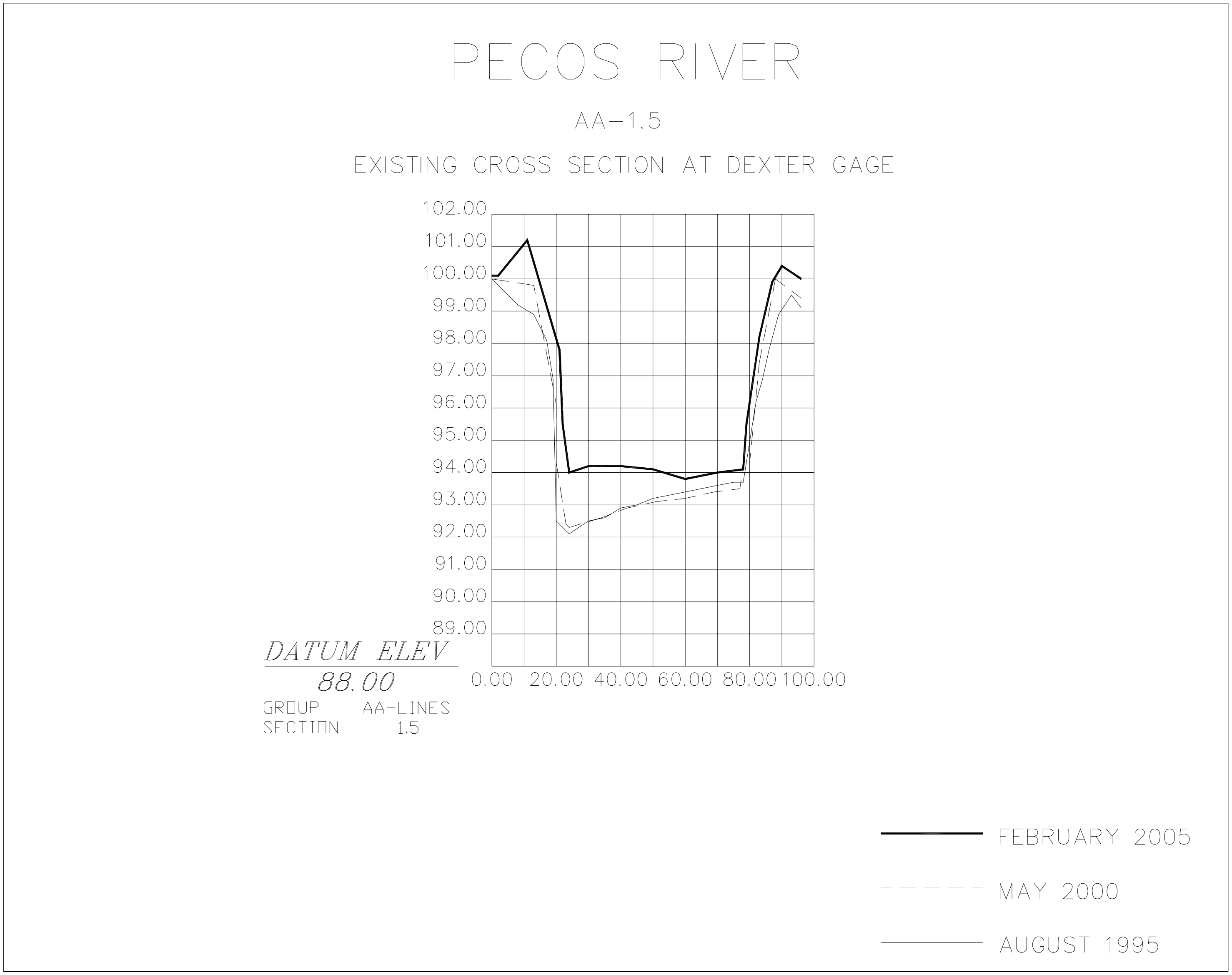
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90.00
89.00
DATUM ELEV
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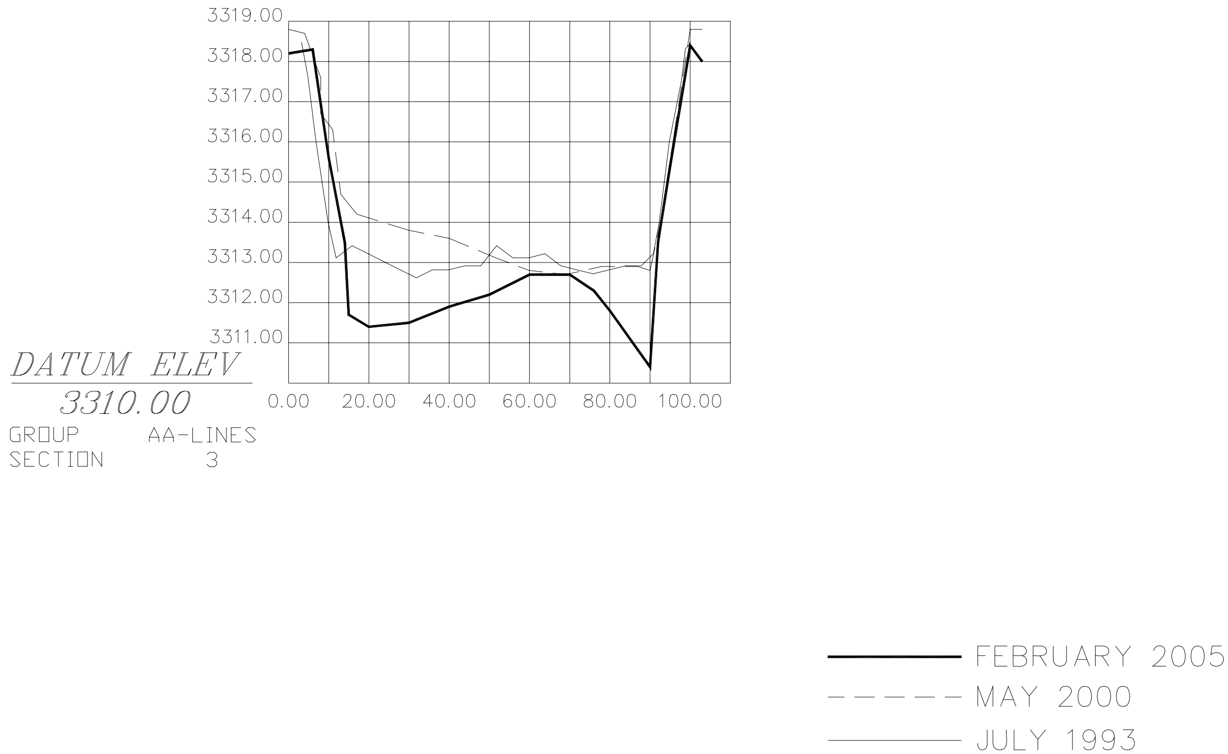
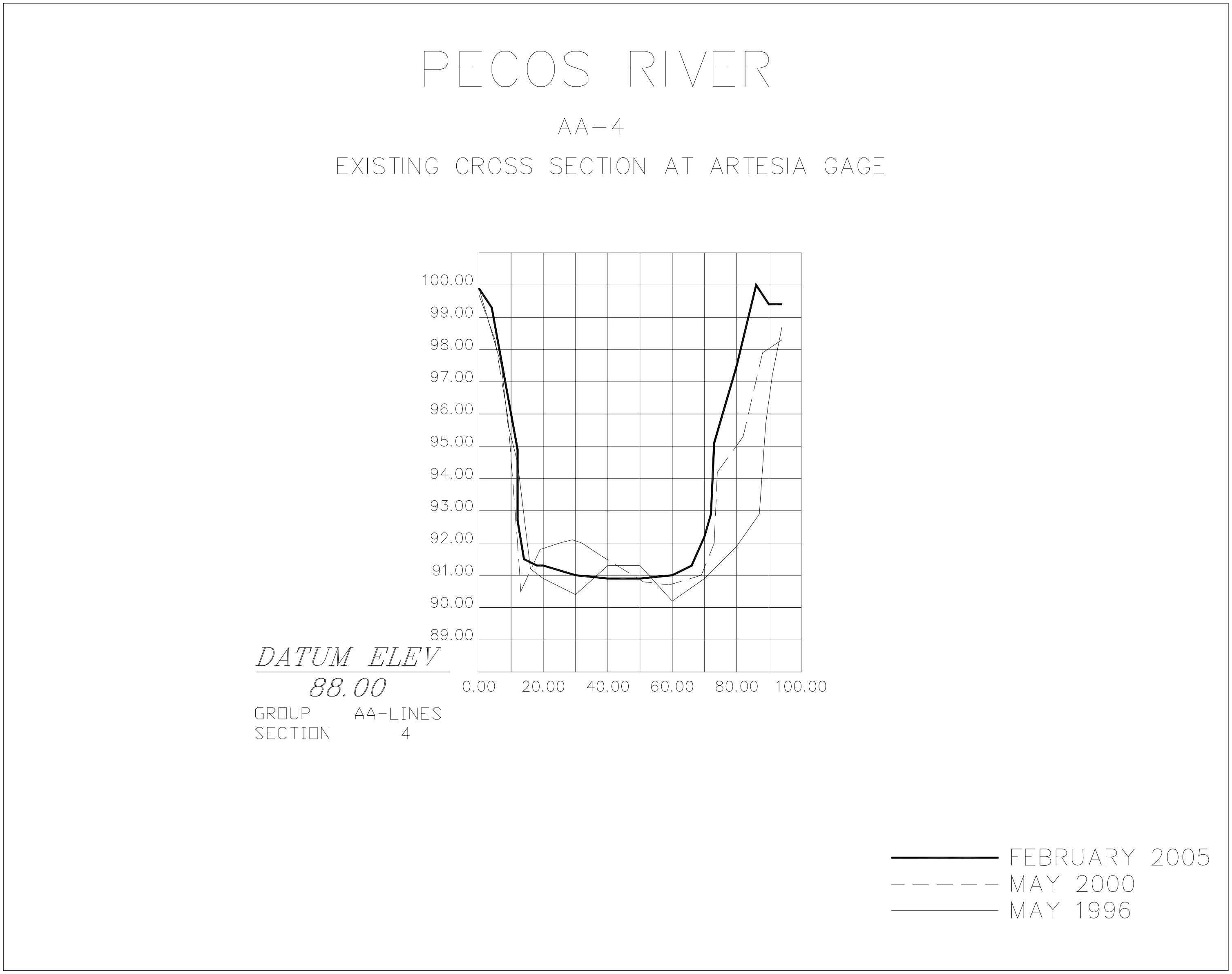
PECOS RIVER

AA–3

EXISTING CROSS SECTION AT LAKE ARTHUR GAGE

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FEBRUARY 2005
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